PETROGRAPHY OF THE PRODUCTIVE COAL SEAMS OF THE BOKARO COALFIELD, BIHAR.

PART I

(TEXT)

By

SATYENDRA M. CASSHYAP, M Sc.

THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN GEOLOGY
AT THE
ALIGARH MUSLIM UNIVERSITY
1961

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INTRODUCTION

Though various sources of power are available in this era of industrialisation, coal continues to maintain its strategic position. It still remains the backbone of all important industries and the chief pendulum in the economy of the country.

The earliest recorded evidence of the discovery of coal in India dates back to 1774 (see Fox, 1931, p. 2) when an attempt was made for the exploitation of coal in the country. The coal industry which remained practically defunct in the years that followed came into prominence only in 1847 when geological investigation of the various coal-bearing formations was undertaken for the first time. As geological work progressed, coalfields were discovered one after another in the different parts of India and the industry became more and more prominent. Today, after the lapse of more than a century and with the discovery of 114 coalfields (K.K. Dutta, private communication), coal industry in India stands vastly changed. It has now taken a firm foot-hold on the economy of the country. The production which was of the order of 281,994 tons about the year 1860, (Simpson & Ball, 1922, p. 49) has now increased to 46.07 million tons (Indian Bureau of Mines, Mineral Production in India, 1958, p. 61).

Although the vegetative origin of coal was well known to the Indian workers, no attempt appears to have been made to study its petrology. Fox (1926, p. 913; 1927, p. 547) was probably the first to examine the optical behaviour of various constituents of Indian coals in thin sections under polarised light. Banerjee (1932) described the microstructure of a few Indian coals from the Jharia and Giridih coalfields. A preliminary microscopic study of certain Indian fusains was made by Chatterjee (1940).

In the years that followed, no serious attempt was made to study the petrology of Indian coals till a fresh stimulus was given to this branch of science by Professor P.N. Ganju, who carried out for the first time detailed petrological investigations of these coals between 1946 and 1950 (Ganju, 1955). In the years that followed Dr. Ganju continued his studies (Ganju, 1955a, 1955b, 1956, 1958, 1960) with the result that much valuable information is now available regarding the nature and origin of Indian coals. Among other contributions mention may be made of those by Chandra (1953, 1954), Pareek (1956, 1958, 1958a), Marshall (1959) and Mukherjee and Dutta (1959). Studies on spores from the Lower Gondwana coals have been carried out in the recent years by Sen (1944, 1953), Virkki (1945), Ghosh and Sen (1948) and Surange et al. (1953).

The Bokaro coalfield was selected for the present study owing to the fact that inspite of its being marked as one of the important coalfields of India, little work has so far been done on the geology and petrology of its various coal seams. The only known publications concerning the geology of this coalfield are those by Hughes (1867), Fermor (1918, 1928), Fox (1934), Gee (1945), Jacob et al. (1958) and Casshyap (1960a). The petrography of some Bokaro coals has been described by Dr. Ganju (1955). Results of the chemical study of these coals have been published by Fermor (1935), Gee (1941), Forrester and Majumdar (1947), Ganju (1955), Marshall (1959), Casshyap (1960) and by various workers of the Fuel Research Institute.

The five important coal seams of the East Bokaro coalfield are the 12-foot, Jarangdih, Kargali, Bermo and Karo seams. Of these only the Kargali and Bermo seams have attracted some attention so far. The Karo seam which is about 100 ft. thick appears to have escaped the attention of geologists with the result that no data is available about this seam.

Of the three important seams of the West Bokaro coalfield, the Kuju seam is the most important, but no published information is available regarding the petrology of any of these seams.

In the course of present investigation, therefore, special attention has been paid to the study of the Kargali, Karo and Kuju seams. The chemical properties of these seams have been examined in detail and an attempt has been made to correlate these results with those of the microscopic studies.

314 samples of coal were collected from all the workable seams of the East and West Bokaro coalfield. Though work is going on mostly in quarries, collection of pillar samples was not found possible due to the excessive thickness of the seams and the restricted facilities available. Every care, however, has been taken to ensure that the samples are representative and cover the maximum possible vertical and horizontal extents. Almost all the working spots in the coalfield were visited and collections were made from as many as 23 quarries and 7 inclines. Two private-owned

inclines could not be visited as their proprietors refused to extend the necessary facilities.

The results of chemical investigation are based on the analysis of 161 typical coal samples. Proximate analysis has been carried out for all these samples. In addition, determination of B.S. Swelling No., caking index and calorific value have been made on various selected samples of each seam. Ultimate analysis has been determined on some samples of the Karo and Kargali seams. A special study has been made on the nature of coke and for this purpose some samples of Karo seam were subjected to the Gray-King low temperature carbonization assay. Grindability tests have also been performed on some specimens of the Karo seam.

The results of the microscopic study are based on the examination of 300 thin and 25 polished sections. Measurements of reflectance have been made on 25 selected samples of the Kargali, Karo and Kuju seams. In order to examine the 'somatic pattern' of each seam, the values of reflectivity so obtained have been plotted against the percentage of respective components present.

The work was carried out in the laboratories of the Geology Department, Aligarh Muslim University, Aligarh. Experiments on chemical analysis were performed in the laboratories of the Chemical Engineering Department, Indian Institute of Technology, Kharagpur. The reflectance studies were made in the laboratories of the Geology Department, I.I.T., Kharagpur.

The author wishes to express his deep sense of gratitude to Professor P.N. Ganju, Ph.D. (Durham), Ph.D. (Lucknow), A.M.I.Min.E., F.G.S., F.N.I., F.P.S., Head of the Department of Geology, Aligarh Muslim University, for kindly suggesting the problem and for his able guidance throughout the work. His thanks are due to the Ministry of Education, Government of India, for the award of a Scholarship from February, 1957, to September, 1958, which enabled him to complete a major part of the work. He is indebted to the Director, Indian Institute of Technology, Kharagpur and to Prof. M.N. Rao, Head of the Department of Chemical Engineering, I.I.T., Kharagpur, for their generous assistance during his work in the Institute. He is also grateful to Prof. T.C. Bagchi, Head of the Department of Geology and Geophysics, I.I.T., Kharagpur, for providing necessary facilities for reflectance studies. Sincere thanks are due to Dr. V.K. Srivastava, Lecturer in Geology, Muslim University, Aligarh, for his useful suggestions on the 'clastic dykes' and to Dr. S.H. Rasul, Dr. N. Ahmad and Mr. I.D. Pant for their encouragement throughout the work.

Thanks are also due to the Chief Mining Engineer, Ranchi, the Superintendent of Collieries, Kargali and to the Proprietors of the private-owned collieries, especially those of the New Selected Dhori and Kuju collieries, for their ready help and co-operation during the author's stay in the Bokaro coalfield.

CHAPTER I

GEOLOGY OF THE BOKARO COALFIELD

The Bokaro coalfield is a narrow faulted trough of Gondwanas extending over a distance of about 40 miles from east to west and 4 to 10 miles from north to south. It lies at a distance of about 2 miles to the west of the Jharia coalfield and encloses an area of about 220 sq. miles. The North Karanpura coalfield is situated on its western side and is separated from it by a stretch of Archaeans about 1 mile wide.

This coalfield was first named by D.H. Williams in 1846 (see Fox 1934, p. 119) after the Bokaro river which runs across it for about 25 miles. Hughes (1867, p. 1), however, preferred a name after the lofty hill of Lugu (Ht. 3203 ft.) - "the most prominent natural object, which meets the eye for miles around, and could never fail to attract attention to itself".

Hughes (1867) was first to map the coalfield in 1867 on a scale of 4 miles to an inch. Though a little less than a century has passed, Hughes work as far as the geology of the field is concerned, remains the most authentic and complete even today. The later studies by Fermor (1918, 1928), Fox (1934), Jacob et al. (1958) and Casshyap (1960a) do not cover much ground.

A brief account of the geology of the coalfield based mainly on the work of Hughes (loc. cit.) is given below.

The following stratigraphical sequence is given by Hughes (p. 1):-

Panchet Series	(Upper Panchets ((Lower Panchets
Damuda Series	(Raniganj Group ((Ironstone Shale Group ((Barakar Group
Talchir Series	

There is a marked inequality in the distribution of the Gondwana rocks which rest on and are surrounded by the Archaeans. While the Barakars occupy a greater part of the field, the younger groups occur in narrow patches outcropping mostly around the Lugu hill. Faults are of common occurrence with the result that the strata are much disturbed and the stratigraphy is complex at various places.

The southern limit of the field is clearly marked by a fault running nearly east to west. Besides there are several cross-faults which bring up the metamorphics against the Damudas. The western and eastern boundaries are generally irregular and rugged being faulted only at few places. These may be regarded as more or less normal junctions. In the same manner the northern limit of the field shows a mixed effect of denudation and faulting. A geological map of the coalfield after T.W. Hughes (<u>loc. cit.</u>) is reproduced in Fig. 1.

The Talchir series occupies a limited area and generally varies in thickness from 20 ft. to 100 ft., but in the Mando (Long. 85°3' E, Lat. 23°42' N) and Indra Jarbah (Long. 85°31' E, Lat. 23°50' N) sections of West Bokaro, the Talchirs show a thickness of 500 ft. Patches of variable width crop out beneath the Damudas along the eastern and western extremities. Small outliers of Talchirs occur in the metamorphics close to the northern boundary near Gobindpoor (Long. 85°56' E, Lat. 23°49' N) and Doda (Long. 85°48' E, Lat. 23°50' N).

The Boulder bed referred to as 'conglomerate bed' by Hughes occurs at or near the base of the Talchirs. Overlying the Boulder bed the fine grained, compact, greenish sandstone and the intercalated bluish needle-like shales form the other important rock types of the Talchir series.

Succeeding the Talchir series with an unconformity is a very thick sequence of fresh water sediments represented by three distinct stages of the Barakar, Barren measures and Raniganj. The Barakar series here is more important than the other two inasmuch as it covers the greatest extent of the field. The conglomerates bed or the 'pebble bed' which forms the basal part of the Barakars gradually passes upwards into the gritty sandstones. The main Barakars appearing above the gritty sandstones consist generally of bands of sandstones and shales intercalated with seams of coal at short intervals. The sandstones which are compact, massive, slightly micaceous and ferruginous at places are white to fawn coloured and contain decomposed felspar.

Fox (1934, p. 120) argues against the usage of the term 'Ironstone Shale' as proposed earlier by Hughes and prefers to call the series as 'Upper Barakars' or 'Middle Damudas'. The Middle Damudas lie conformably over the Barakars and are mainly composed of slightly calcareous and highly micaceous sandstones which are similar to the sandstones of the Raniganj stage. Lenticles of carbonaceous shale occur sometimes in the sandstones.

The Raniganj stage is thinly developed and often rests directly over the Barakars with a definite unconformity. The rocks of this group generally consist of moderately coarse grained and massive sandstones which are frequently intercalated with shales and thin coal seams.

All the productive coal seams of the Bokaro coalfield are confined to the Barakar series of rocks. The Barakars of the East Bokaro coalfield are more important economically and contain some of the thickest seams of India like the Kargali (80 ft. - 120 ft.), Karo (80 ft. - 100 ft.) and Bermo (45 ft.) seams. The coal seams of the Raniganj stage are thin and poor in quality and are accordingly not being worked.

Overlying the Damuda series in the central part of the field, there is another group of fresh water strata, the Panchets, which rest over the Raniganj stage with a slight unconformity. The Lower Panchets forming the base of the Lugu hill are so different in their lithological characters from the Upper Panchets that Hughes was tempted to propose an unconformity between those two subdivisions. The Upper Panchets appearing at the top of the Lugu hill have been correlated with the Mahadevas of the Narbada

Valley by Hughes and the Dubrajpur beds of the Rajmahal Hills by Fox (1934, p. 121).

Fermor (as cited in Fox, 1934, p. 122) carried out extensive investigations on the coal measures of the Bokaro coalfield in 1916 and 1917. He discovered as many as 29 coal seams in the Barakars of ~~the~~ East Bokaro, out of which only 19 seams were over 4 feet thick. His subdivisions of the Barakar coal measures are given below:-

Strata and total coal and seams.	Chief coal seams.	Rock between seams.
<u>Middle Damudas</u> or noncoal-bearing strata (Barren Measures) chiefly sandstones and shales.		2,750 ft.
		278 ft.
<u>Lower Damudas</u>	No. 25, L seam, 16 ft.	
Upper sandstones and shales with thin coal seams 1,050 ft., rock 982 ft., coal 68 ft. in ten seams.		56 ft.
	K seam, 13 ft.	41 ft.
	J seam, 5 ft.	26 ft.
	I seam, 6 ft.	214 ft.
	H seam, 4 ft.	126 ft.
	G seam, 6 ft.	285 ft.
	No. 15, F seam, 12 ft.	94 ft.
	E seam, 6 ft.	140 ft.
Middle sandstones and shales with thick coal seams 1,095 ft., rock 863 ft., coal 232 ft. in six seams.	No. 13, D seam, 58 ft.	125 ft.
	No. 12, seam, 27 ft.	124 ft.
	No. 11, seam, 46 ft.	302 ft.
	No. 10, C seam, 3 ft.	23 ft.
	No. 9, B seam, 29 ft.	149 ft.
	No. 8, A seam, 69 ft.	140 ft.
Lower grits, sandstones and shales with thin coal seams, rock 396 ft., coal 25 ft. in seven seams.	....	421 ft.
Basal grits and conglomerates.	....	128 ft.

Fox (1934) gave a general account of the Bokaro coalfield indicating especially the number of productive coal seams, conditions of working, total out-put and reserves.

Dykes of dolerite and mica-peridotite are nearly as common as in the Jharia coalfield. At places about 4 to 6 ft. thick bands of coal have been completely converted into "Jhama". Some of the dykes resembling mica-peridotites in hand specimen, have been described by the author (Casshyap, 1960b) as 'elastic dykes'. 'Burnt' outcrops of coal are common in this coalfield (Fermor, 1918, p. 52).

Jacob et al. (1958) have carried out a brief investigation on sedimentological aspects of Gondwanas of the East Bokaro and Jharia coalfields. Their studies in the East Bokaro coalfield were confined to the eastern-most part around Chapri and Emlo. The officers of the Geological Survey of India have recently mapped the coalfield on a scale of 4 inches to a mile, but their account has not been published till now.

THE PRODUCTIVE COAL SEAMS

The first report on the nature of various coal seams in the Bokaro coalfield was given by Fox in 1934 (loc. cit.). Although considerable exploitation of coal has taken place since then, no further work appears to have been published. In the light of field work conducted by the author it is considered important to deal with each productive coal seam separately.

The coal seams do not lie at any great depths and they generally crop out and maintain a low gradient. The angle of dip on an average varies from 6° to 10° increasing to 25° at places. The general direction of dip is towards the south but it is reversed near the southern boundary where the strata dip towards the north or north-west. The geological features of most of the seams are such that surface quarrying is considered more favourable as compared to the underground mining.

East Bokaro Coalfield

The important coal seams in the East Bokaro coalfield in their downward succession as given by Fox (loc. cit., p. 121), are as follows:-

12-foot A seam		
Kargali seam	..	100 ft. thick
Bermo seam	..	40 ft. "
Karo seam	..	80 ft. "

A sketch map showing the outcrops of all the workable seams in the East Bokaro coalfield published by the Geological Survey of India is reproduced in Fig. 2. The position of various collieries in the map has been marked by the author.

12-foot A Seam

In the opinion of the author, Fermor's No. 15F seam (see p. 10) refers to the 12-foot seam. This seam occurring in a limited area varies in thickness from 10 ft. to 12 ft. and has been worked out extensively so that it is nearing exhaustion. It is one of the seams being mined by the Kargali colliery and is wholly worked through inclines.

Kargali Seam

This is the most important seam which underlies the 12-foot seam and is separated from it by about 240 ft. thick intervening strata. The seam has a wide aerial extension and runs through a distance of about 12 miles from Swang near the Lugu hill in the west to Dhori near the eastern extremity. The outcrop of the seam, however, is not continuous throughout. In its great extension the seam displays an enormous variation in thickness from 41 ft. at Swang to 121.6 ft. in Jarangdih Shaft No. XV (Fox 1934, p. 123). In one section of the Bokaro colliery, the Kargali seam has a record thickness of 126 ft. At Dhori, the seam distinctly splits into two, the strata in-between being about 40 ft. thick; the parting thins down to 2 ft. in the Kargali colliery, Quarry No. 3, which is situated in a westerly direction at a distance of about 2 miles from Dhori. The splitting actually starts from Quarry No. 1 of the Kargali colliery.

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Mining of coal in the East Bokaro coalfield has been restricted practically to the Kargali seam for the last 50 years. Out of the six collieries working this seam, those of the Swang, Jarangdih, Bokaro and Kargali are State-owned collieries, while the Pipradih and Dhori collieries owned by Anderson and Wright, are being worked by M/S Bokaro Ramgarh Ltd. Since 1958 a new colliery known as the Kathara colliery has come into existence. It is also State-owned and is quarrying the Kargali seam which is about 70 ft. thick here. The general direction of dip in this area is from south to north. Dr. Fermor's estimate of the total reserves of coal in the Kargali seam after making necessary deduction for faults, picking and natural coking, are of the order of 365 million tons. Fox, however, believes that the reserves are safely upward of 500 million tons. About 85 per cent of the total production of coal in the Bokaro coalfield is obtained from the Kargali seam.

Bermo Seam

This seam varies in thickness from 40 to 45 ft. and is frequently interbedded with bands of shale. It is being quarried at two places near Bermo and Dhori; the Bermo colliery is owned by the Damodar Valley Corporation and the Dhori colliery by Anderson and Wright. The dip which is about 5° to 10° at Bermo, steepens near Dhori to about 18°. The total reserves of the Bermo seam estimated by A.B. Dutta (see Damodar Valley Corporation and Fuel Research Institute Joint Publication, 1952, p. 3) are of the order of 219,950,000 tons.

Karo Seam

The Karo seam underlies the Bermo seam and is separated from it by about 470 ft. thick intervening strata. There are generally two outcrops of the Karo seam, the Top Karo and the Bottom Karo and the total thickness of the two varies from 80 ft. to 100 ft. The author (Casshyap, 1960a) has described the geology and nature of the Karo measures in the eastern extremity of the coalfield. A detailed account of this is given in the next chapter.

Jarangdih Seam

Fox has referred in his work (loc. cit.) to the above four seams only. After the Jarangdih pits were flooded in 1934, working of the Kargali seam had to be stopped. In 1935 work started in 3 inclines on another 20 ft. thick seam locally known as the Jarangdih seam. The seam has a variable strike direction and its outcrop runs only for a short distance. The dip is generally 12^{o} to 13^{o}NW, but at some places it is 18^{o}NW; occasionally it is towards the west.

Apart from the seams described above there are several minor seams which may possibly be exploited economically.

West Bokaro Coalfield

The potentialities of coal in the West Bokaro coalfield are not very promising as the area is highly disturbed by a large number of faults which occur frequently and at short intervals. As a result of careful examination, the Bokaro Ramgarh Ltd. consider that they have proved as many as 21 seams in the West Bokaro area.

The distribution of coal in blocks A, B and C west of Kedla and block G (Kuju), about 4 miles southwest of Kedla, as given by Fox (1934, p. 132), is shown in Table No. 1. Out of these only No. 9 seam of Kedla, No. 10 seam of Mandu and the Kuju seam show good quality coal.

TABLE NO. 1: DISTRIBUTION OF COAL SEAMS IN THE WEST BOKARO COALFIELD

Block	Seam	Area	Thickness (Feet)	Quantity (Million tons)
A (Kedla)	7	3,200	19	182
	9	2,500	6	6
	21	700	18	4
B (north)	7	2,000	10	8
(south)	10	2,500	10	10
C		not fully proved		
D		" " "		
E		" " "		
F		" " "		
G (Kuju)	Kuju	2,000	9 (Top)	7½

(Seams No. 7, 9, 10 and 21 are numbered from the base of the Barakars).

It is important to note that seam numbers of the West Bokaro coalfield are not the same as those of the East Bokaro as no correlation has been made (Fox, loc. cit., p. 133).

The outcrops of quarriable coal seams in the West Bokaro coalfield are shown in the map in Fig. 3. Coal is not being exploited systematically in the West Bokaro coalfield. Most of the collieries are under the control of Bokaro Ramgarh Ltd. and the important West Bokaro colliery at Ghato has been taken over recently by Messrs Tata Ltd.

No. X and No. XI Seams

Of the various seams of the West Bokaro coalfield, No. X, No. XI and the Kuju seams only have been studied. Seam No. X which is being worked in the Arrah and Sarubera collieries is about 14 ft. thick and has a dip of 17°NW. Seam No. XI is about 25 ft. to 30 ft. thick and is being worked in the Sarubera colliery. In Table No. 1 no reference has been made to seam No. XI, but the seam which overlies No. X seam in the Sarubera colliery is locally called seam No. XI.

Kuju Seam

The Kuju seam is distributed over a large area and is being worked in the collieries of Pindra, Datma, Topan, Banvar, Morpa, Kuju and Haisaghara.

In the Morpa colliery the seam is about 18 ft. to 20 ft. thick, in the Kuju colliery it is about 35 ft. thick and in the Haisaghara colliery it is nearly 27 ft. thick. The seam is being worked in quarries and inclines but at no place is its full thickness exposed.

CHAPTER II

THE KARO MEASURES

The Karo seam is an important coal seam of the East Bokaro coalfield. It extends over a stretch of about 7 miles from Bermo to Turio near the eastern extremity of the coalfield and varies in thickness from about 80 ft. to 100 ft. The only published account of this seam is based on the works of Hughes (1867) and Fermor (see Fox, 1934). This seam has been studied by the author in detail in the area lying between 23°45' and 23°47' N. Lat. and 86°01' and 86°03' E. Long. which may be regarded as the type area for this seam.

The only subdivision of the Lower Gondwanas present in this area are the Barakars which show more or less the same general characters as in the other parts of the coalfield. The greater part of the area is occupied by sandstones of which two varieties can be distinguished in the field. The whitish, coarse grained and compact variety is more prominent and extends over a considerable area to the north of the Damodar river forming hills and dales; the less significant variety is the overlying brown, micaceous sandstone which is confined to the northern bank of the river. The latter group of sandstones is felspathic, slightly ferruginous and thinly bedded. In the north, near Makoli, the whitish sandstones are slightly gritty. This textural variation in the first group of sandstones is quite significant as it clearly shows that the gritty sandstones around Makoli belong to the third subdivision of the Barakars - "Lower grits, sandstones and shales" as classified by Fermor (see Fox, 1934, p. 122). The whitish sandstones are massive and show two sets of joints along the dip and strike.

The other rocks of the Barakars include bands of sandy to carbonaceous shales with interbedded coal seams. Good exposures of the shales are seen in the river bed towards the southern bank where some well preserved impressions of Glossopteris were collected.

The general trend of the Karo measures and their distribution in the type area is shown in the map in Fig. 4. Over a greater part of the area, the direction of strike of the main seams is between 125° to 135° and the dip is in the southerly direction, varying from 15° to 22°.

The two main seams of the Karo measures are known as the Top Karo and the Bottom Karo which are 50 ft. and 80 ft. in thickness respectively. The two are separated by a band of thinly bedded shale varying in thickness from 30 ft. to 40 ft. A characteristic feature of both the seams is the frequent occurrence of partings of shale and sandstone, some of which are quite prominent. The topmost portion of the Bottom Karo forms a sort of narrow escarpment on the southern bank of the Damodar river where it is nicely exposed. In this region the Bottom Karo shows effects of disturbance. Layers of coal are contorted and crumpled showing distinct plications as shown in Plate 1, Fig. 1. In the map published by the Geological Survey of India and reproduced in Fig. 2, two faults have been shown in this region running approximately NNE - SSW across the coal seam and the river bed.

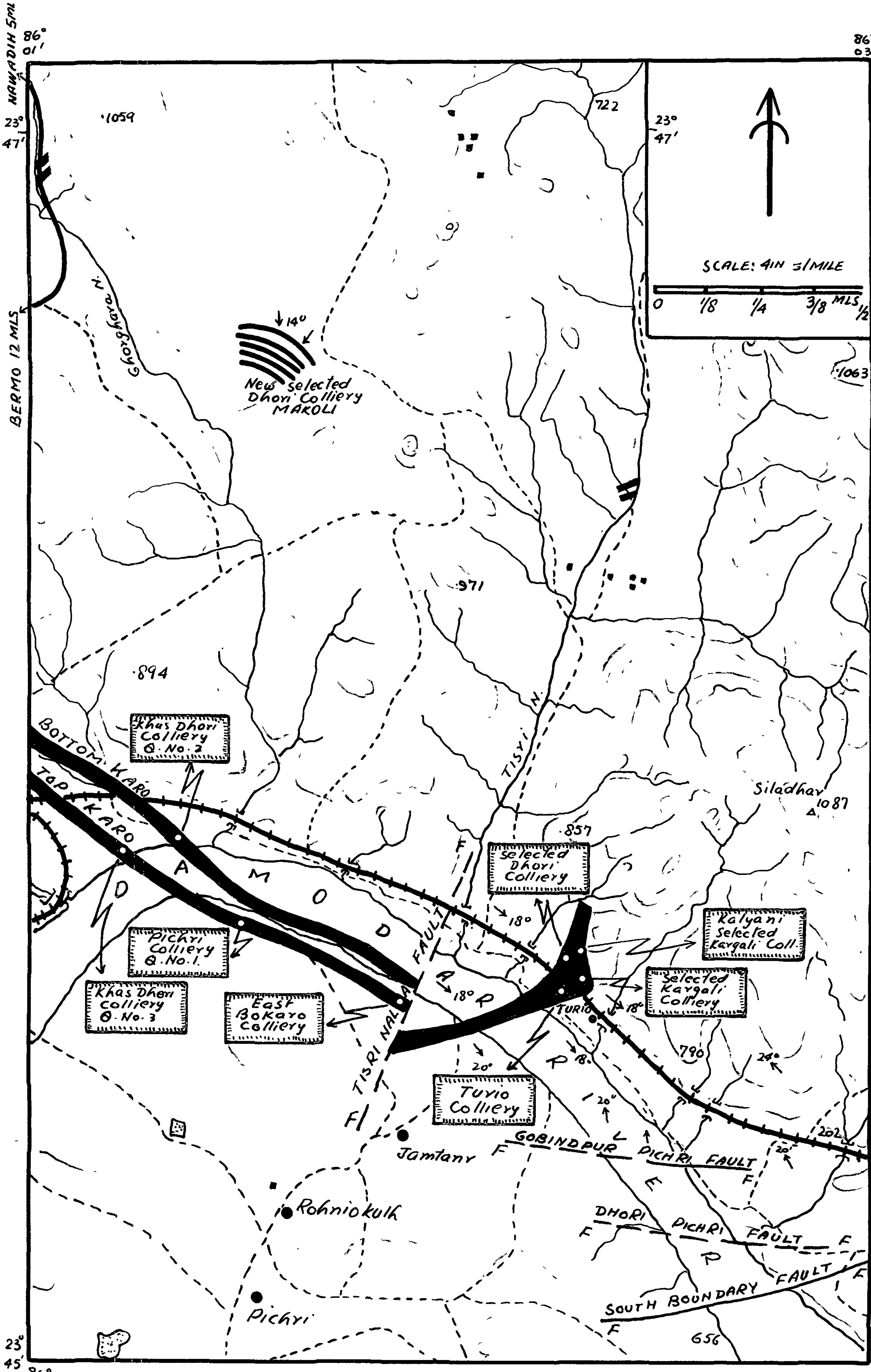

FIG.—4 DISTRIBUTION OF COAL SEAMS IN THE KARO MEASURES OF MAKOLI AREA.

There is, however, no evidence of displacement anywhere along the escarpment excepting the crumpling of coal which may have resulted by shear fracture (Billings, 1954, p. 91). In the East Bokaro colliery, not far from the southern bank, the Top Karo seam displays signs of severe disturbance of the type of squeezed folding indicating that the seam was subjected to enormous pressure in this region.

The Karo measures are affected by a number of faults in the eastern region some of which have produced abrupt changes in the strike and dip. One such major change is noticed first after the Teesri nala fault which runs approximately in a north-south direction and passes probably through the East Bokaro colliery. The general trend of the strike east of this fault is more or less in a north-south direction and the strata dip towards the east or south-east. There is, however, no significant change in the amount of dip. About half a mile east of the Turio colliery another reversal in the direction of dip is observed. The beds now dip towards NW or W at an angle varying from 20° to 25°. This reversal in the direction of dip has most probably been brought about by the South Boundary fault as well as by the two parallel faults of Dhori-Pichri and Gobindpore-Pichri running in an east-west direction. Further eastwards, upto the eastern and south-eastern extremities of the coalfield, the general trend of the strata remains practically the same.

An important feature of the geology of Karo measures which deserves careful attention is that only one of the two seams is found to outcrop east of the Teesri nala fault. Several close traverses were made but no exposure of the other seam was found. The Geological Survey of India map reproduced in Fig. 2 also shows the outcrop of only one seam in this region. As both the seams of the Karo measures are affected by the fault, the disappearance of one seam in this region appears due to the effect of this fault. Taking into consideration the fact that the thickness of the coal seam in the Turio colliery situated to the east of this fault is 100 feet, it appears probable that the seam exposed in the eastern region is the Bottom Karo seam. But a correct correlation is possible only when the area is explored thoroughly and bore holes are put on either side of the fault at appropriate places. In order to avoid confusion, the coal seam which outcrops east of the Teesri nala fault has been disgnated by the author as the Eastern Karo seam.

The outcrop of the Eastern Karo seam could not be traced further northwards because there is no established working in this region and the area is inaccessible.

A 'burnt' outcrop of the Bottom Karo has been found along the north bank of the Damodar river near Khas Dhori colliery. The burnt product is compact and tough and yellowish to ashy in appearance. At places the bands of shale which are associated with it also show some effects of fusion. Fermor (1918, p. 52) has noted the abundance of 'burnt' outcrops in this coalfield and is much impressed by their prominence. He suggests that this area is most suitable for studying baked and fused strata.

Coal Seams in the Makoli Region

In the northern part of the area between Ghoraghara nala and Teesri nala, productive seams of coal have been found to occur in an area of nearly 150 acres in the Makoli Property. Hughes (1867, p. 13) has mentioned the occurrence of only a burnt seam in this locality.

As many as five seams of total thickness of about 50 ft. occur here interbedded with partings of shale and sandstone of varying thickness. Their outcrops are slightly arcuate and the dip is in a S to SSW direction at an angle of 14° to 15° as shown in the map in Fig. 4. Outcrops of coal are also encountered in the Ghoraghara nala in the north-west and along the Teesri nala near the paddy fields in the east. The actual extent of these seams could not be traced as the narrow outcrops are exposed in a very small area. It is difficult to say anything regarding the stratigraphic position of these widely separated outcrops of coal. The complete sequence of the coal bearing strata in the Makoli area is as follows:-

		Thickness in feet
Alluvium	..	10
Coal	..	2
Sandstone	..	2.5
Coal seam	..	12
Shale	..	28
Coal seam	..	5
Shaly band	..	10
Coal seam	..	11
Shale parting	..	27
Coal seam	..	9
Shale mixed with coal	..	27
Coal seam	..	13
		166.5

The most commonly occurring rock type of this region is the white gritty sandstone which probably belongs to Fermor's third subdivision of the Lower Damudas viz. "Lower grits, sandstones and shales". Fermor has recorded the occurrence of a few thin coal seams in this subdivision (see Fox, 1934, p. 122).

The coal seams of Makoli are being worked entirely by the New Selected Dhori colliery. Seven collieries situated around the banks of the Damodar in an area of about 1 sq. mile are working the main seams of the Karo measures. The position of the various collieries is shown in the map in Fig. 4.

The highest production of coal in this area comes from the New Selected Dhori colliery from where about 100 to 150 tons of coal are raised per day.

CHAPTER III

THE CLASTIC DYKES

The injection of detrital material into stratified or other rock bodies at normal temperature is a well known sedimentary feature. Sandstone or clastic dykes as they are commonly known, have been studied with considerable interest. The mechanism of emplacement of such dykes and the provenance of the material composing them are interesting problems which arise in their study.

References to clastic dykes in the Indian geological literature are few. Fermor (1914) noted the occurrence of a 'sandstone' dyke at Lechman Jharia (No. 9, Kuresia coalfield). He considers it to have been formed by an infilling from the above. While describing similar dykes in the Rohtas limestone of Markundi, Son Valley, Auden (see Fermor, 1931) has observed that these dykes follow the joint direction and that the sand was introduced after consolidation of the limestobe. He, however, does not make any reference to the direction of their emplacement. Recently, Rao (1956) has reported the occurrence of a 'clastic' dyke in the Serampur colliery, Giridih coalfield. The dyke rock which in the opinion of the author was injected from below is made up of coarse black arkose with sharp angular fragments of coal at the margins.

No clastic dykes have been reported from the Bokaro coalfield till now, but mica peridotite dykes are known to occur abundantly (Hughes, 1867; Fermor, as cited in Fox, 1934).

In the Kargali colliery, Quarry No. 2, three clastic dykes varying in width from about 1 ft. to 2 ft. have been found cutting across the entire thickness of the coal seam almost vertically in N 20° E direction. Running almost parallel to these dykes there is a clastic dyke about 2 ft. wide in Quarry No. 1 and another dyke about 1.5 ft. wide in the Bokaro colliery, Quarry No. 7, cutting across the Kargali seam in the same manner.

Plate 1, Fig. 2 shows the lower portion of the Middle dyke in the abandoned Quarry No. 2.

PETROGRAPHY

Clastic Dykes from Kargali Colliery, Quarry No. 2

The Western Dyke

The rock is blackish in colour, compact and medium to fine grained. Angular to subrounded quartz occurs abundantly and shining flakes of mica are common. Fragments of coal are seen embedded all over the surface of the specimen. The specific gravity varies from 2.42 (K_2D_1) to 2.88 (K_2D_3).

In thin sections, the rock is made up of two essential components - the detrital particles and the chemically precipitated iron carbonate cement -

varying from 34.97 to 64.89 per cent and 35.0 to 65.0 per cent respectively. For determining the modal composition of the specimens, three random sections from each were analysed using a Leitz six-spindle integrating stage. The following table gives the average modal composition of three specimens:-

Specimen No.	Quartz	Micas	Rock Fragments	Coal Fragments	Cement
K_2D_1	55.68	3.42	1.80	3.99	35.00
K_2D_2	50.15	2.60	1.26	0.29	45.70
K_2D_3	30.98	2.43	0.53	1.05	65.00

Quartz varies from 30.98 to 55.68 per cent and is the most important constituent of the framework; its grains vary from 0.04 mm. to 1.2 mm. in diameter, but the dominant size is between 0.15 mm. to 0.35 mm. It shows much variation in shape and roundness being mostly subangular to subrounded, though grains with corroded and indented margins and those with straight edges and sharp re-entrant angles are not uncommon.

The angularity of most of the grains has been produced as a result of their replacement by iron carbonate cement, a fact illustrated in Plate 2, Figs. 1, 2, 3 and 4. Fig. 2 shows a quartz grain in the lower middle right-hand side which has been deeply corroded along its margins. The cement has replaced the mineral on all sides and also along the cracks in the grain. The whole piece in fact appears disrupted into several small segments which show crenulated and indented margins. In addition there are several other grains in the upper half and lower left-hand side which show irregular borders. It appears that the angularity in these grains is secondary rather than original. Pettijohn (1936, pp. 284, 326, 653) while discussing cementation problems in sandstones suggests that carbonate cements often have a tendency to encroach upon quartz grains. Some striking evidences of the corrosion of quartz by carbonate cement have been furnished by Nicholas (1956) and more recently by Ganju and Srivastava (1961).

In all the specimens studied, packing of the grains is not found to be 'normal'. Contacts per grain vary from 0.60 to 0.65 in specimen No. K_2D_1 (Plate 2, Fig. 1) and from 0.45 to 0.25 in K_2D_2 (Plate 2, Figs. 2 and 3). Gaither (1953, p. 193) has proposed that in a random thin section of a freshly deposited sand, there are approximately 0.85 contacts per grain. When many grains are not in contact, the framework is termed 'disrupted' or 'broken' (Pettijohn, 1956, p. 283), as in the specimens mentioned above.

The quartz grains are both of igneous and metamorphic derivation but those of igneous origin are more common. Metamorphic quartz grains are generally lensoid in shape and show marked sweeping extinction and regular mineral inclusions.

Among micas, muscovite is more prominent and occurs in elongated laths or finely divided shreds, ranging in size from 1.3 mm. to 0.04 mm. Some elongated flakes of muscovite are sharply bent as illustrated in Plate 2, Fig. 4 which shows in the upper left-hand and lower right-hand sides laths of muscovite bent round the grains of quartz. At places they appear to have been forcibly torn apart along the cleavage planes, the intervening space being filled with carbonate cement. Two laths of mica lying in the top left-hand and lower right-hand sides in Plate 3, Fig. 1 illustrate this feature clearly. The muscovite piece lying in the left-hand centre in Plate 3, Fig. 2 is frayed at the ends and the flakes are slightly bent at the extremities with the cement penetrating in between the torn parts. This feature shows that the splitting of flakes was a post-depositional feature and that the mineral is of detrital origin. Biotite is less common and occurs in small subhedral grains as seen in the lower right-hand side in Plate 3, Fig. 2.

Quartzite fragments which are subangular to subrounded occur sporadically (0.5 to 1.80 per cent) and vary in size from 0.20 mm. to 0.25 mm. Fragments of coal which also form a constituent of the framework are generally sparsely distributed (0.29 to 1.05 per cent), but sometimes they occur abundantly (3.09 per cent). Plate 3, Fig. 3 shows fragments of coal which are incorporated in the dyke rock.

The chemically precipitated siderite forms the principal cement. It occurs in fine crystalline state as shown in Plate 3, Figs. 3 and 4. It is unaltered generally but in one specimen the sideritic material has been completely altered to limonite as illustrated in Plate 2, Fig. 1. In this specimen small clayey patches are associated with limonite cement and these probably represent remnants of the original rock matrix. In the same specimen crypto-crystalline silica resembling chalcedony also occurs in small quantity and this has probably formed at a later stage due to the partial replacement of limonite by silica. On account of these features the rock may be called a sideritic sandstone.

The Middle Dyke

This dyke is about 1.5 ft. wide and occurs approximately 60 ft. east of the dyke described above. The rock is steel grey to black in colour, compact and medium to fine grained. Grains of quartz and flakes of mica are scattered throughout. Its specific gravity is 3.15.

In thin sections it is observed that the material constituting the cement far exceeds the detrital components which comprise only 21.54 per cent of the rock constituents. The modal analysis of the rock is as follows:-

		Per cent
Quartz	..	19.13
Micas	..	2.33
Rock fragments	..	0.07
Cement	..	78.46

In this case also quartz is the dominant constituent of the framework though its actual quantity is much less as compared to that in the Western dyke. The size of quartz grains is smaller and varies from 0.04 mm. to 0.20 mm., the majority of grains being about 0.10 mm. in diameter. The grains of the framework are not in contact as is clear in Plate 4, Fig. 1. Mica flakes which constitute 2.33 per cent of the rock are much smaller in size (0.25 mm. to 0.04 mm.) and quartzite fragments are present to the extent of 0.07 per cent only.

The cement is composed of finely crystalline siderite and it constitutes over 78.4 per cent of the total bulk of the rock.

The Eastern Dyke

This dyke is situated about 100 ft. east of the Middle dyke and is about one foot wide. The dyke is hard, dark grey in colour and medium to fine grained. Mica flakes occur only sparsely and small fragments of coal are seen at places. Its specific gravity is 3.60.

The detrital components constitute only about 9.0 per cent of the rock. The cement which is sideritic in composition is very abundant. Plate 4, Fig. 2 exhibits a typical specimen showing quartz grains, small fragments of coal and minute flakes of muscovite as the main detrital constituents. The modal analysis is as follows:-

		Per cent
Quartz	..	5.86
Micas	..	0.25
Coal fragments	..	2.87
Cement	..	91.00

Quartz and micas occur only as vestiges, varying in size from 0.02 mm. to 0.15 mm. and 0.04 mm. to 0.10 mm. respectively. The borders of the grains are fairly corroded. The rock may be called an ironstone.

Clastic Dyke from Quarry No. 1, Kargali Colliery

In all its general characters this rock closely resembles the rock of the Eastern dyke from Quarry No. 2, described above. The total detrital constituents appear further reduced and amount to 7.53 per cent only. Quartz which comprises 3.76 per cent is the chief constituent and its grain size varies from 0.04 mm. to 0.20 mm. Micas and bits of coal occur rarely and amount to 0.68 per cent and 1.88 per cent respectively.

Coarsely crystalline siderite is the only cement present and it constitutes as much as 92.45 per cent. Plate 4, Fig. 3 shows that crystalline siderite is predominant and includes fairly corroded quartz grains and flakes of mica. This rock also is an ironstone.

Clastic Dyke from Quarry No. 7, Bokaro Colliery

This dyke varies in width from about 1.0 ft. to 1.5 ft. and cuts across the Kargali seam in the same manner as do the other dykes.

The detrital constituents comprise 15.8 per cent, out of which quartz alone constitutes as much as 12.6 per cent with its grain size varying from 0.18 mm. to 0.16 mm. Mica flakes constitute 3.2 per cent and vary in size from 0.19 mm. to 0.02 mm. Plate 4, Fig. 4 shows a general view of the rock in a thin section.

ORIGIN OF THE DYKES

The nature of the cement and detrital constituents and their mode of occurrence in the rocks described above form an interesting part of their study. The cement is generally more abundantly present than the detrital constituents. The contacts per grain in all the cases are low, the highest value observed being 0.65. This shows that the framework of all the dyke rocks is disrupted. Whether the framework was disrupted originally or after deposition is a point which requires consideration.

There is hardly any evidence in favour of the post-depositional disruption of the framework. The number of contacts per grain nowhere come near to 0.85 which is an important parameter for recognizing a 'normal' framework of the rock. It is difficult to imagine that replacing agencies would produce such a wholesale disruption of the framework without leaving a vestige of the 'normal' framework. On the other hand, the presence of several rounded to subrounded grains and remnants of clayey patches may be cited as evidences in favour of the view that the framework was originally disrupted and the clayey material formed the interstitial matrix.

The fluidity factor determine the type of framework that is produced in a rock (Pettijohn, loc. cit., p. 288). In normal sedimentation the sediment/fluid ratio is very low, i.e. the sorting is rapid and complete and a compact framework is produced. It is only when this ratio is very high and the sediment is in the form of a high density fluid that a disrupted framework is produced. The original disruption of the framework in the dyke rocks can, therefore, be explained only when it is assumed that the injecting material consisted of a high density fluid. Thus it is reasonable to infer that the dyke material before its emplacement was in the form of a thick slurry, being essentially made up of detrital constituents together with a large quantity of silt and clay. There is ample evidence to show that the slurry was injected with force. Many detrital mica flakes are sharply bent and fractured and their ends are frayed. This shows that they were subjected to intense pressure and the clay and silt was injected along their cleavage planes splitting the mica flakes into shreds. The presence of coal fragments in almost all the dyke rocks can also be cited as an evidence in favour of forceful injection of the material. A similar mode of injection of clastic dykes in igneous and sedimentary rocks has been advocated by Anderson (1914), Shrock (1948) and Vitanage (1954).

The replacement of the interstitial clayey matrix and detrital constituents by iron carbonate solutions was a post-depositional feature and this process disrupted the framework further in many cases. Whether the replacement by these solutions took place immediately after the emplacement of dyke material or much later is difficult to say.

The sideritic solutions, however, did not react uniformly every where. In the dyke in Quarry No. 1 and also in the Eastern dyke, Quarry No. 2, the replacement is so perfect and the disruption of the framework so pronounced that quartz and mica occur as vestiges. The whole rock is dominated by crystalline siderite and may be called an ironstone. On the other hand, in the Western dyke in Quarry No. 2, the replacement is less pronounced and the percentage of cement is only 35.0. The specific gravity of the respective specimens also shows a close relationship with the increasing siderite percentage; the highest value of 3.60 is in the ironstone and the lowest of 2.42 in the one having the siderite percentage of 35.0. The clayey matrix in all the dykes appears to have been replaced first due to the fine size of its particles.

Whether the injection of dykes took place from the top or from the bottom of the seam is difficult to say and requires further study. It has not been possible to ascertain the relationship of the dyke to the underlying rocks as no such contacts are exposed. There is, however, one evidence which can possibly throw some light on this question. The rocks underlying the coal seam are carbonaceous black shales while the overlying rocks are coarse to medium grained sandstones which are slightly ferruginous and often micaceous. If the injection had taken place from below the dyke rocks would show some similarities with the underlying black shales. On the other hand, the dykes are essentially sandstones at some places and the constituents of their framework resemble very closely those of the overlying sandstones. Owing to this fact it may be tentatively suggested that the injection of the slurry into the pre-existing cracks of the coal seam took place probably from above.

CHAPTER IV

CHEMICAL CHARACTERISTICS OF COALS

It is generally agreed that the chemical characters of coal are closely related to its petrological constitution. In order to study the problems of coal preparation and utilization, it is very helpful to ascertain the nature of petrological constituents of coals vis-a-vis their chemical properties.

The chemical properties of coal vary according to the percentage of carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorous. The variation in the amount of mineral matter present has an important effect on the chemical properties. The qualitative analysis of these elements is an exact process requiring elaborate apparatus and careful techniques. The proximate analysis, on the other hand, is a quicker process involving the determination of moisture, volatile matter, ash and fixed carbon (by difference). The results convey adequate information regarding the commercial value of the solid fuel.

Besides the proximate and ultimate analyses several other laboratory tests including the determination of the calorific value, caking index, swelling index, the Gray-King assay and the Hardgrove Grindability tests have to be performed in order to obtain accurate data regarding the quality of coal.

The workable coal seams of the Bokaro coalfield have probably been analysed chemically by the mining companies concerned or by the Fuel Research Institute, but no detailed data has been published. Consequently the available information regarding the chemical characters of these coals is very scanty. Fox (1934, pp. 126-127) quoted some proximate analyses of the Kargali seam from the Swang, Joint (now known as the Bokaro colliery) and Dhori collieries. The coals from the Dhori colliery were found to be of caking quality. Subsequently Fermor (1935, p. 359) made some Gray-King assay tests on the Kargali seam. In 1947, some washability tests were carried out by Forrester and Majumdar (1947, pp. 101-106) on the Karo seams of the East Bokaro coalfield and on the Leiyo, No. X and No. XI seams of the West Bokaro coalfield. In 1952, detailed studies of the Bermo seam including coking and washability tests were made by the Fuel Research Institute (Damodar Valley Corporation and Fuel Research Institute Joint Publication, 1952; Report, Fuel Research Committee, 1952, p. 6). In the same year the Fuel Research Institute carried out blending tests on coals of the Kargali seam from the Kathara and Bokaro collieries. A few analyses of the Kargali seam have also been reported in the 'Indian Coals' published by the Fuel Research Institute (F.R.I. Publication, 1948, p. 8). More recently, Dr. Ganju has quoted 26 proximate analyses of the Kargali seam (Ganju, 1955, p. 37).

Thus it is clear that the chemical studies of these coals are confined to the Kargali seam. It is also clear that no attempts have been made to correlate the results of chemical study with the microscopic constitution of these coals.

The following productive coal seams have been studied in the course of present work:-

			Thickness in feet
East Bokaro Coalfield	12-foot A seam	..	12
	Jarangdih seam	..	20
	Kargali seam	..	100
	Bermo seam	..	45
	Karo seam	..	80 - 100
West Bokaro Coalfield	Kuju seam	..	40
	No. XI seam	..	30
	No. X seam	..	20

A total number of 161 samples have been analysed chemically. The distribution of these samples is as follows:-

Kargali seam	..	80 samples
Karo seam	..	40 "
Kuju seam	..	13 "
12-foot A seam	..	4 "
Jarangdih seam	..	4 "
Bermo seam	..	5 "
Coal seams of Makoli	..	10 "
No. XI seam	..	3 "
No. X seam	..	2 "
		161

The location of the various collieries from where samples were collected is shown in maps reproduced in Figs. 2 and 3 and in the map in Fig. 4. The Kargali seam being the most important seam has been studied in greater detail. The Karo and Kuju seams have also been examined on similar lines because adequate information regarding the chemical properties of the seams is not available. The Bermo seam has not been examined in detail as the Fuel Research Institute has published a comprehensive report on this seam (Damodar Valley Corporation and Fuel Research Institute Joint Publication, 1952).

Calorific value was determined in 51 selected samples, caking index in 52 and B.S. swelling number in 75 samples. Carbon and hydrogen percentages were determined in 20 and sulphur in 25 samples. In addition, Grindability tests and Gray-King low temperature carbonization assay have been carried out on 15 and 6 specimens of the Karo measures, respectively.

During the last forty years or so considerable improvements have been made in the methods of analysis of coal (Fuel Research Survey paper No. 2, 1923; British Standard Methods paper No. 404, 1930; No. 420, 1931; No. 496, 1933; No. 705, 1936; No. 735, 1937; Fieldner and Selvig, 1938; and B.S. Specification No. 1016). The methods followed in the present investigation are the same as detailed in the British Standard Institution, Specification No. 1016, as revised in 1957. It may be added that the Fuel Research Institute of India also adopts the same specifications.

EAST BOKARO COALFIELD

THE KARGALI SEAM

A total number of 80 samples, collected from four different collieries, were analysed. The calorific value, caking index and swelling number were determined in 29, 25 and 47 samples, respectively. The ultimate analysis was determined in 14 samples.

The 80 samples analysed are distributed in the different collieries as follows:-

Colliery	Working thickness of the seam (in feet)	No. of samples analysed
SWANG		
Quarry No. 2	40	6
BOKARO		
Quarry No. 7	90	34
Quarry No. 2	35	7
KARGALI		
Quarry No. 1	80	10
Quarry No. 2	75	9
Quarry No. 3	70	10
DHORI		
Incline No. 7	30	2
Quarry No. 1	20	2

Chemical Analysis

Figs. 5 and 6 show sections of the Kargali seam from 8 quarries and the horizon of the samples analysed. The sections of the Swang colliery, Quarry No. 2, and Kargali colliery, Quarry No. 2, were kindly supplied by the Managers of the respective collieries.

Results of the proximate analysis and coking properties appear in Table No. 2 and those of the ultimate analysis in Table No. 3.

The variation in the different constituents is as follows:-

Moisture

The moisture is below 1.0 per cent in majority of cases, the average value being 0.5 per cent. In the Bokaro colliery, Quarry No. 7, the moisture content shows a marked tendency to decrease with depth. On an average, it is 0.8 per cent in the top and 0.2 to 0.3 per cent in the bottom sections of the seam. In the collieries lying eastward, the average moisture content throughout the vertical thickness is comparatively low being 0.2 to 0.4 per cent.

Ash

The average percentage of ash and its distribution from west to east in the different collieries is as follows:-

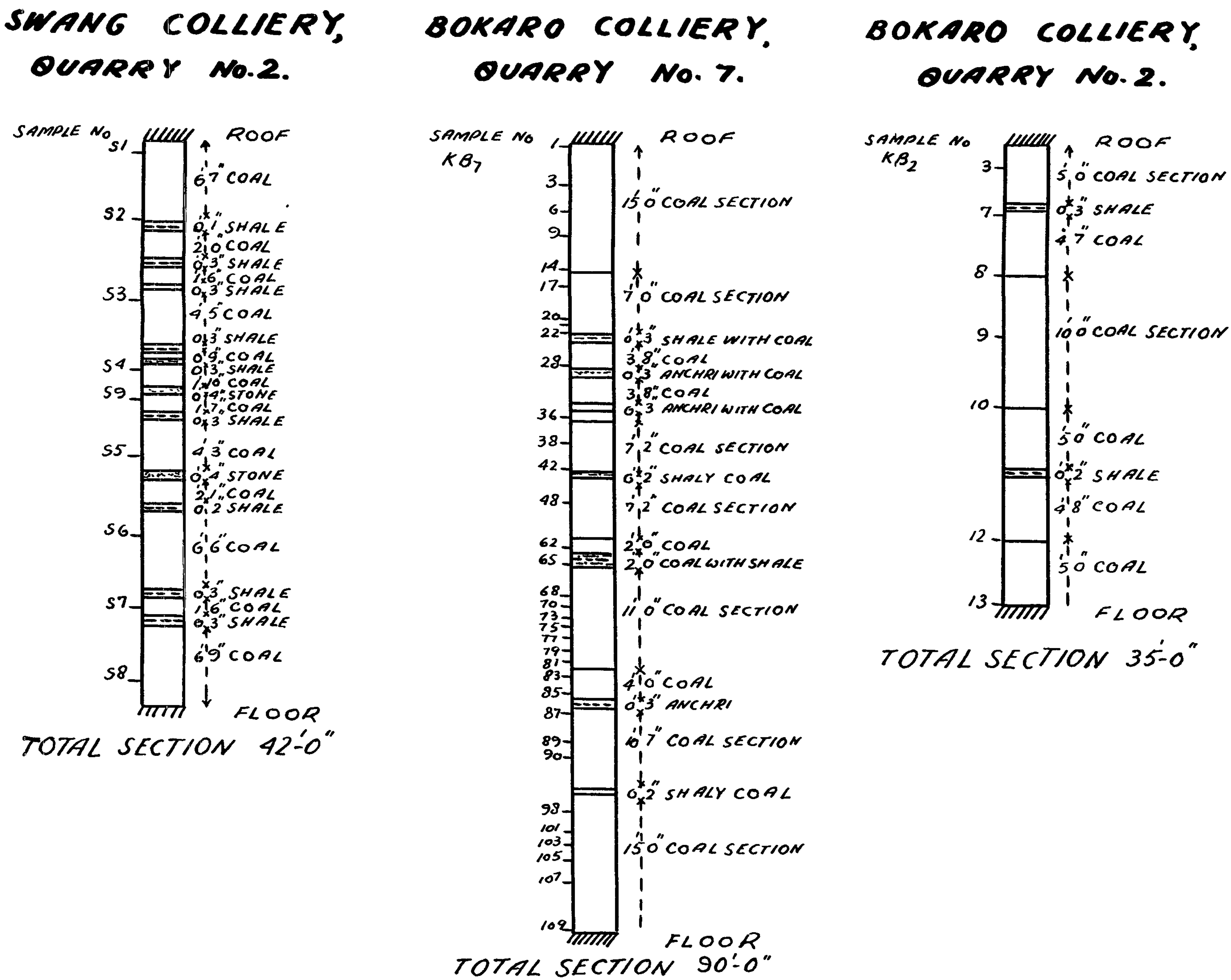

FIG. 5. SECTION OF THE KARGALI SEAM IN THE SWANG AND BOKARO COLLIERIES.

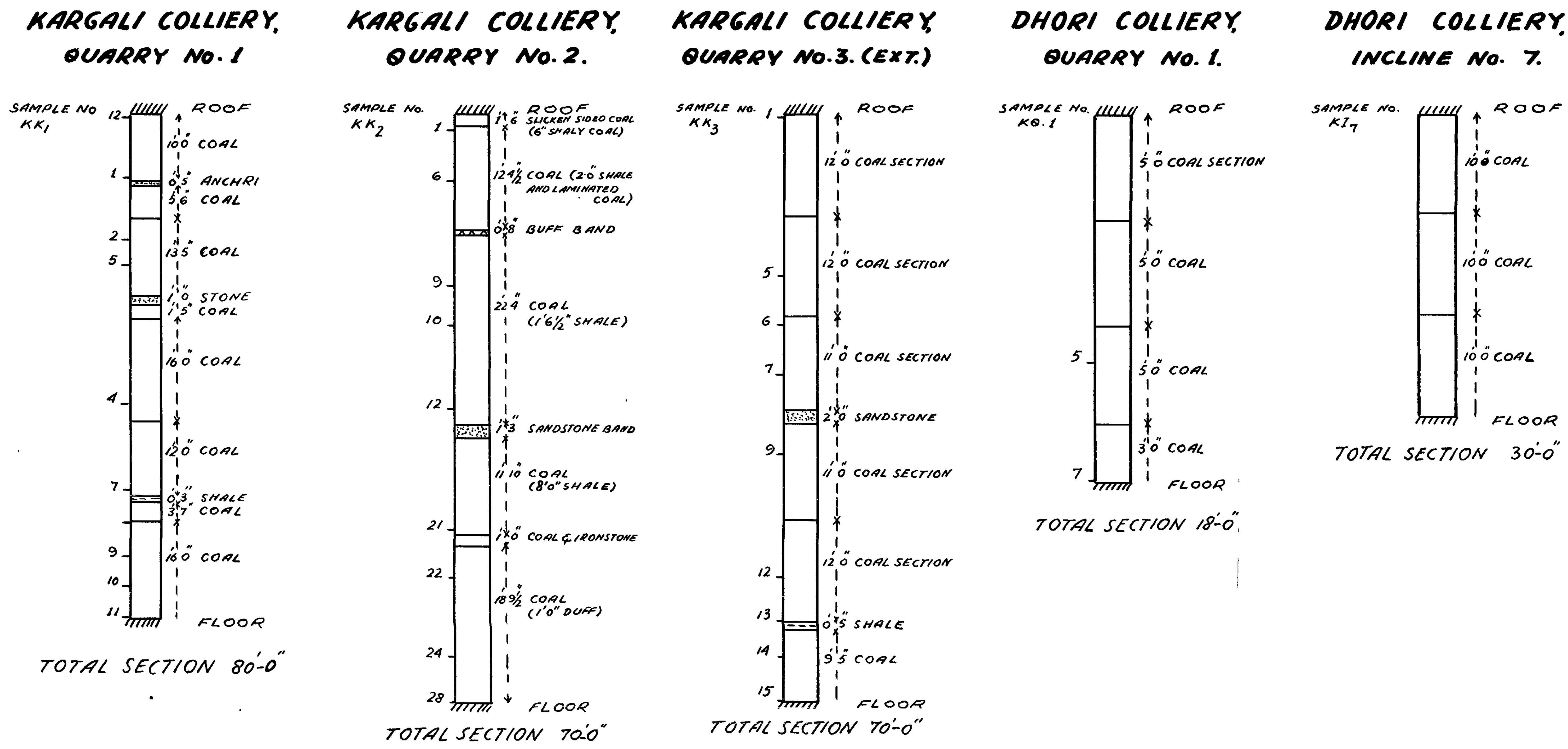

FIG. 6. SECTION OF THE KARGALI SEAM IN THE KARGALI AND DHORI COLLIERIES.

TABLE No. 2: RESULTS OF THE PROXIMATE ANALYSES AND CO KING CHARACTERS OF THE KARGALI SEAM.

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B. Th. U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
1	S1	1.4	19.5	28.7	50.4	36.3	63.7	-	-	White with greyish tinge	Af	Slightly swoll., metall. lustr., porous.	-	4½	Swang Coll. Quarry No. 2.
2	S2	0.6	11.9	32.0	55.5	36.6	63.4	13,338	15,243	Dirty white	Cf-Cg	Fairly to good swoll., porous.	21	7½	-do-
3	S4	0.3	9.8	32.8	57.1	36.5	63.5	-	-	White with greyish tinge.	Cf	Fairly swoll., porous.	-	7	-do-
4	S9	1.1	14.8	28.9	55.2	34.3	65.7	-	-	-do-	Af	Non-swoll., mod. hard.	-	-	-do-
5	S6	0.4	13.2	31.1	55.3	36.0	64.0	-	-	Greyish white	Af	Non-swoll., fairly aggl.	-	2½	-do-
6	S8	0.3	14.9	31.3	53.5	36.9	63.1	12,990	15,318	Whitish grey	Af	Aggl., non-swoll.	19	5	-do-
7	KB7/1	0.9	11.0	31.3	56.8	35.4	64.6	-	-	Dirty white	Af	Non-swoll., fairly aggl.	-	-	Bokaro Coll. Quarry No. 7.
8	KB7/3	0.8	8.0	31.3	59.9	34.6	65.4	13,804	15,136	White	Af-Gp	Non-swoll., fairly strong, lustr. metall.	19	4½	-do-
9	KB7/6	0.6	10.4	28.0	61.0	31.4	68.6	-	-	Greyish white	Af	Very strongly aggl.	-	-	-do-
10	KB7/9	0.8	12.3	29.0	57.0	33.3	66.7	-	-	Whitish grey	Gp-Af	Strongly aggl., slightly swoll., non-fiss.	-	3	-do-
11	KB7/14	0.5	14.9	27.6	57.0	32.6	67.4	-	-	Greyish white	Af	-do-	17	-	-do-
12	KB7/17	1.2	7.4	28.6	66.2	31.2	68.8	-	-	Pinkish	Aw	Less strong, fiss.	-	-	-do-
13	KB7/20	2.0	19.2	27.0	51.8	34.3	65.7	-	-	Light pinkish	Af	Strong, non-swoll.	-	-	-do-
14	KB7/21	1.0	4.7	31.4	66.9	33.1	66.9	14,685	15,572	Whitish grey	Cf	Fairly swoll., porous.	20	6	-do-

TABLE NO. 2: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARGALI SEAM (CONTINUED).

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B.Th.U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
15.	KB7/22	0.8	19.8	27.7	51.7	34.8	65.2	-	-	Pinkish white	Cp	Slightly swoll., strong.	17	2	Bokaro Coll., Quarry No. 7.
16.	KB7/28	0.8	7.1	30.9	61.2	33.6	66.4	-	-	Pinkish white	Cf	Fairly swoll., non-fiss., lust. metall.	-	3½	-do-
17.	KB7/36	0.8	31.2	25.3	42.7	37.2	62.8	-	-	Pinkish	Af	Non-swoll., fairly aggl.	-	-	-do-
18.	KB7/38	0.6	8.9	29.5	61.0	32.6	67.4	-	-	Pinkish	Aw	Weakly aggl., broken piece.	-	-	-do-
19.	KB7/42	0.2	24.4	28.8	47.3	37.3	62.7	10,959	14,734	Yellowish white	Af	Fairly aggl., non-swoll.	18	2	-do-
20.	KB7/48	0.2	18.3	25.5	66.0	31.3	68.7	-	-	Pinkish white	Aw	Non-swoll., broken piece.	-	1	-do-
21.	KB7/62	0.4	19.0	25.6	55.0	31.7	68.3	-	-	Pinkish white	Aw	-do-	-	-	-do-
22.	KB7/65	0.5	36.8	20.2	42.5	32.1	67.9	-	-	Greyish white	Af	Non-aggl., fairly strong.	-	-	-do-
23.	KB7/68	0.3	12.0	29.5	58.2	33.6	66.4	-	-	Dirty white	Cp	Poorly swollen, fairly strong.	-	4½	-do-
24.	KB7/70	0.5	26.4	24.6	48.5	33.6	66.4	10,765	14,726	Greyish white	Aw	Non-aggl., fairly strong, dull.	16	NS	-do-
25.	KB7/73	0.8	18.9	26.5	53.8	33.0	67.0	-	-	Dirty greyish	Af	Non-swoll., strong.	-	-	-do-
26.	KB7/75	0.7	6.8	30.9	61.6	33.9	66.1	-	-	Pale	Cf	Fairly swoll., strong, lust. metall.	20	6	-do-
27.	KB7/77	0.4	7.7	30.3	61.6	32.9	67.1	-	-	Pinkish white	Cf	-do-	-	5½	-do-
28.	KB7/79	0.3	23.8	27.5	48.4	36.3	63.7	-	-	White	Cp	Poorly swoll., strong, slightly porous.	-	-	-do-

TABLE NO. 2: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARGALI SEAM (CONTINUED).

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B. Th. U./lb.		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
29.	KB7/81	0.4	16.5	28.6	54.5	34.4	65.6	-	-	Pale	Cp	Poorly swoll., Strong, Slightly porous.	-	4½	Bokaro Coll., Quarry No. 7.
30.	KB7/83	0.2	13.8	25.0	61.0	28.1	71.9	13,310	15,620	Pink	NAb	Non-aggl., non-swoll., strong.	-	-	-do-
31.	KB7/85	0.2	27.8	25.2	46.8	35.0	65.0	-	-	Greyish white	Aw	Non-swoll., weakly aggl.	-	-	-do-
32.	KB7/87	0.4	11.6	25.8	62.2	29.3	70.7	13,277	15,087	Pinkish	Aw	-do-	17	-	-do-
33.	KB7/89	0.7	13.1	29.1	57.1	33.7	66.3	-	-	White	NAb	Non-swoll., non-aggl., slightly fiss.	-	-	-do-
34.	KB7/90	0.5	12.8	29.5	57.2	35.2	64.8	-	-	Pinkish white	Cf	Fairly swoll., mod. strong, slightly porous.	-	5	-do-
35.	KB7/98	0.3	19.6	28.5	51.6	35.6	54.4	-	-	Greyish white	Cp	Poorly swoll., non-fiss.	-	4	-do-
36.	KB7/101	0.2	17.1	29.0	53.7	35.1	64.9	-	-	Pinkish	Cf	Fairly swoll., hard, metall. lust.	-	5½	-do-
37.	KB7/103	0.3	8.2	31.6	59.9	34.5	65.5	13,503	14,757	Pale	Cf	Fair to good swoll., metall. lust., porous.	20	6	-do-
38.	KB7/105	0.4	16.8	29.5	52.3	35.6	64.4	-	-	Pinkish white	Cf	-do-	-	4½	-do-
39.	KB7/107	0.2	14.1	29.2	56.5	34.1	65.9	-	-	-do-	Cp	Poorly swoll., mod. hard, slightly porous.	-	-	-do-
40.	KB7/109	0.2	16.0	30.5	53.3	36.4	63.6	11,792	14,740	-do-	Cf	Mod. swoll., fairly hard, silvery white.	-	5½	-do-
41.	KB2/3	0.9	12.2	31.7	55.2	37.6	62.4	13,461	15,552	White	Af	Non-swoll., aggl., dull.	20	2	Bokaro Coll., Quarry No. 2.
42.	KB2/7	1.0	21.9	27.2	50.0	35.1	64.9	-	-	Brownish	Af	-do-	-	-	-do-

TABLE NO. 2: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARGALI SEAM (CONTINUED).

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B. Th. U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
43.	KB2/8	0.9	15.8	30.2	53.1	36.7	63.3	-	-	Pinkish white	Cf	Mod. swoll., silvery white.	-	3	Bokaro Coll., Quarry No. 2.
44.	KB2/9	1.0	11.7	26.9	60.4	30.8	69.2	-	-	White	Af	Non-swoll., mod. strong.	-	-	-do-
45.	KB2/10	0.9	18.0	28.4	52.7	34.8	65.2	-	-	Chocolate	Gp	Poorly swoll., slightly hard, porous.	-	-	-do-
46.	KB2/12	1.1	17.0	29.6	52.3	36.1	63.9	-	-	White	Cf	Mod. to fairly swoll., slightly porous.	20	5½	-do-
47.	KB2/13	1.9	14.0	25.3	58.8	30.1	60.9	13,049	15,146	Greyish white	Af	Fairly aggl., non-swoll., dull.	-	2	-do-
48.	KK1/12	0.4	20.3	28.6	50.7	36.1	63.9	12,863	16,221	Creamish	Cf	Fairly swoll., porous.	19	3½	Kargali Coll., Quarry No. 1. (Extension)
49.	KK1/1	0.7	15.0	24.5	59.8	29.1	70.6	-	-	White	Af	Non-swoll., fairly aggl., lust. metall.	-	-	-do-
50.	KK1/2	0.7	14.1	27.3	57.9	32.0	68.0	13,063	15,333	Pinkish white	Aw	Non-swoll., weakly aggl., dull.	-	1½	-do-
51.	KK1/3	0.4	16.7	26.9	56.0	31.9	69.1	12,981	15,600	Creamish	Af	Fairly aggl., slightly porous.	-	-	-do-
52.	KK1/5	0.6	17.4	24.5	57.5	29.9	70.1	-	-	Creamish	Af	-do-	-	-	-do-
53.	KK1/4	0.3	17.1	24.6	58.0	29.8	70.2	12,493	15,125	White with violet tinge.	Aw	Weakly aggl., dull.	17	NS	-do-
54.	KK1/7	0.6	24.2	24.7	50.5	32.8	67.2	-	-	Creamish white	Gp	Poorly to fairly swoll., slightly porous.	-	-	-do-
55.	KK1/9	0.6	25.7	24.3	49.4	33.0	67.0	10,929	14,829	-do-	Af	Grey, dull, slightly swoll., hard.	18	2	-do-
56.	KK1/10	0.2	16.4	28.2	55.2	33.8	66.2	-	-	-do-	Cf	Fairly swoll., slightly porous.	-	-	-do-

TABLE NO. 2: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARGALI SEAM. (CONTINUED).

S. No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific Value B.Th.U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
57.	KK1/11	0.5	25.3	22.8	51.4	29.2	70.8	15,310	15,310	Creamish white	Cf	Good swoll., lust. metall., porous.	-	4½	Kargali Coll., Quarry No. 1 (Extn.
58.	KK2/1	0.7	13.3	28.0	58.0	32.5	67.5	-	-	Pinkish white	Cp	Slightly swoll., greyish,	-	3½	Kargali Coll., Quarry No. 2.
59.	KK2/6	0.7	16.1	27.3	55.9	32.8	67.2	14,907	14,907	Pinkish white	Af	Strongly aggl., black.	-	3	-do-
60.	KK2/9	0.5	20.4	24.8	54.3	31.3	68.7	-	-	White	Af	Strong, non-swoll., black.	-	-	-do-
61.	KK2/10	0.7	19.5	23.8	56.0	29.8	70.2	-	-	Pinkish	Af	-do-	17	-	-do-
62.	KK2/12	0.6	21.7	27.3	50.4	35.1	64.9	11,501	14,802	Creamish	Cf	Fairly swoll., good cell structure.	-	4½	-do-
63.	KK2/21	0.2	22.0	26.3	51.5	23.8	66.2	-	-	Creamish white	Cf	-do-	-	4½	-do-
64.	KK2/22	0.2	18.0	26.1	53.9	32.8	67.2	12,165	14,871	Pink	Af	Aggl., non-swoll.	-	-	-do-
65.	KK2/24	0.3	26.7	23.2	49.8	31.7	68.3	-	-	Creamish white	Cp	Slightly swoll., porous, black.	18	3	-do-
66.	KK2/28	0.3	17.8	21.9	60.9	26.7	73.3	12,571	15,118	Greyish white	Af	Strongly aggl., black.	-	1½	-do-
67.	KK3/1	0.3	24.2	24.9	50.6	32.9	67.1	11,590	15,350	Creamish white	Af	-do-	16	-	Kargali Coll., Quarry No. 3.
68.	KK3/V/1	1.3	1.2	29.8	67.7	30.6	69.4	15,160	15,549	Creamish	Cg	Good swoll., porous.	-	2½	-do-
69.	KK3/5	0.3	10.7	26.7	62.3	30.0	70.0	-	-	Greyish white	Af	Strong, slightly swoll.	20	5½	-do-
70.	KK3/7	0.3	19.5	26.0	54.2	32.4	67.6	-	-	Chocolate	Af	-do-	-	NS	-do-

TABLE NO. 2: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARGALI SEAM.

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B. Th. U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
71.	KK3/8	0.9	6.8	30.3	62.0	32.8	67.2	-	-	Creamish	Cf	Fairly swoll., hard.	-	6½	Kargali Coll., Quarry No. 3.
72.	KK3/9	0.3	12.1	29.0	58.6	33.1	66.9	13,252	15,128	Light Chocolate	Cf	Good swoll., slightly porous.	20	5	-do-
73.	KK3/12	0.4	14.0	25.2	57.4	29.4	70.6	-	-	-do-	Gp	Poorly swoll., grey.	-	2½	-do-
74.	KK3/13	0.3	31.6	22.3	45.8	32.7	67.3	9,818	14,810	Pink	Gp	-do-	18	-	-do-
75.	KK3/14	0.2	21.6	20.7	57.5	26.4	73.6	-	-	Greyish white	NAb	Non-swoll., black, fiss.	-	-	-do-
76.	KK3/15	0.3	16.5	23.8	60.4	28.4	71.6	12,937	15,348	-do-	Aw	Weakly aggl., non-swoll.	17	1½	-do-
77.	KI7/3	0.2	29.0	21.1	49.7	29.8	70.2	-	-	Creamish white	Af	Non-swoll., strong.	-	-	Dhori Coll., Inclined No. 7.
78.	KI7/9	0.2	26.9	23.2	49.7	31.8	68.2	11,195	14,885	Pinkish white	Gp	Slightly swoll.	18	1	-do-
79.	KQ1/5	0.4	11.8	23.9	63.9	27.2	72.8	13,117	14,962	Pink	NAb	Non-swoll., weak.	-	-	Dhori Coll., Quarry No. 1.
80.	KQ1/7	0.4	14.0	28.6	56.8	33.6	66.4	-	-	Greyish white	Cf	Fairly swoll., slightly porous.	19	4½	-do-

Colliery	Range of ash on dry basic (per cent)	Average ash (per cent)
SWANG		
Quarry No. 2	9.8 to 19.8	14.1
BOKARO, Quarry No. 7		
Top. 33 ft.	4.9 to 31.5	13.2
Mid. 36-63 ft.	6.8 to 37.0	19.4
Bottom 65-90 ft.	12.8 to 19.7	14.4
KARGALI		
Quarry No. 1	14.2 to 25.9	19.6
Quarry No. 2	13.4 to 26.8	19.6
Quarry No. 3	12.1 to 31.7	17.8
DHORI		
Incline No. 7	27.0 to 29.1	28.0
Quarry No. 1	11.8 to 14.0	12.9

Though there is a wide variation in the percentage of ash in the Kargali seam (from 4.9 to 37.0 per cent, on dry basis), the majority of coals have medium to fairly high ash (14.0 to 19.0 per cent approximately). While in the coals of the Swang and Bokaro collieries the average ash content is 14.1 to 16.0 per cent, in the Kargali colliery it increases slightly, the average being 19.0 per cent. Further eastward, in Incline No. 7 of the Dhori colliery where the Top band of the Kargali seam is worked, the percentage of ash increases further, the average being 28.0 per cent. It may be mentioned that in the Dhori colliery a 40 ft. thick parting of shale splits the Kargali seam into the Top and Bottom bands.

A part of the ash is finely disseminated in the coal, but a fair proportion occurs in the form of separate bands of carbonaceous shale locally known as 'Anchri'. The prevalent colour of the ash is creamish which shows that there is a general deficiency of ferric oxides and also that it can stand high temperatures without fusion. Pinkish coloured ash is also common but that of chocolate colour is rare.

Volatile Matter

From Table No. 2 it is clear that the volatile matter (d.a.f.) of the coals of Kargali seam is generally between 29.0 to 33.0 per cent, rarely exceeding 37.0 per cent. It is, therefore, inferred that this seam has medium to high volatile coals.

The average volatile percentage on dry-ash-free basis in the different collieries is as follows:-

Colliery	Range of volatile per cent (d.a.f.)	Average volatile per cent (d.a.f.)
SWANG		
Quarry No. 2	34.3 to 36.9	36.1
BOKARO, Quarry No. 7		
Top	31.2 to 37.2	33.5
Middle	29.1 to 37.3	33.4
Bottom	34.1 to 36.4	35.0
KARGALI		
Quarry No. 1	29.1 to 36.1	32.3
Quarry No. 2	26.7 to 35.1	31.4
Quarry No. 3	26.4 to 33.1	30.8
DHORI		
Incline No.7	29.8 to 31.8	30.8
Quarry No. 1	27.2 to 33.6	30.4

While there does not appear a systematic variation of volatile matter with depth, there seems to exist regional variation in this constituent from east to west. This variation, however, is not much pronounced. The average volatile content in the eastern-most Dhori colliery, Quarry No. 1, is 30.4 per cent and it increases to 36.1 per cent in the western-most Swang colliery, which is at a distance of about 10 miles from the Dhori colliery.

Carbon, Hydrogen and Sulphur

Carbon, hydrogen and sulphur determinations were made on 14 samples and their results are given in Table No. 3.

The percentage of carbon on dry-ash-free basis varies from 84.76 to 90.04. The lower limit of carbon in the coking coals of bituminous rank is about 82.5 per cent on dry-mineral-free basis (Spooner and Mott, 1937, p. 96; Indian Standard Institution, 1955, p. 10). The coals of the Kargali seam, therefore, fall well within the range of good coking coals.

The hydrogen percentage varies from 4.85 to 5.42 (d.a.f.). This is the chief constituent of volatile matter so that when hydrogen increases, volatiles also increase.

The total sulphur in all the samples analysed has been found to vary from 0.52 to 1.06 per cent (d.a.f.). Sulphur is also included in the category of combustible substances and constitutes a part of the

TABLE NO. 3: RESULTS OF THE ULTIMATE ANALYSIS OF THE KARGALI SEAM

S.No.	Sample No.	as calculated (per cent)			d. a. f. (per cent)		
		H	C	S	H	C	S
1.	S/2	4.72	75.00	0.69	5.36	85.14	0.79
2.	KB7/3	4.72	79.32	0.91	5.30	88.45	1.00
3.	KB7/21	5.06	85.11	0.68	5.32	89.43	0.72
4.	KB7/89	4.27	78.23	0.42	4.98	90.04	0.52
5.	KB7/103	4.69	78.14	0.84	5.28	87.02	0.92
6.	KB7/109	4.55	71.20	0.89	5.42	84.76	1.06
7.	KK1/2	4.39	75.05	0.72	5.12	88.00	0.84
8.	KK1/3	4.37	74.32	0.72	5.16	89.22	0.81
9.	KK1/4	4.07	73.28	0.63	5.10	89.47	0.76
10.	KK1/11	4.06	65.51	0.65	5.31	89.64	0.88
11.	KK2/22	4.34	69.64	0.56	5.20	86.92	0.58
12.	KK2/28	3.98	73.15	0.48	4.85	89.04	0.58
13.	KK3/6	4.58	78.22	0.72	5.13	87.63	0.81
14.	KK3/13	3.56	55.76	0.58	5.22	87.52	0.85

volatile matter. Thus a general increase in the percentage of volatile matter has been observed with an increase in the sulphur content.

Calorific Value

The calorific value was determined on an average for one sample per 15 ft. of coal in each colliery. The average calorific value as determined on dry-ash-free basis varies as follows:-

Colliery	Calorific value (B.th.u./lb) (as determined)	Calorific value (B.th.u./lb) (d.a.f.)
<u>SWANG</u>		
Quarry No. 2	13,164	15,281
<u>BOKARO, Quarry No. 7</u>		
Top	14,244	15,354
Middle	10,862	14,730
Bottom	13,191	15,036
<u>KARGALI</u>		
Quarry No. 1	11,927	15,343
Quarry No. 2	12,010	14,799
Quarry No. 3	12,290	15,112
<u>DHORI</u>		
Incline No.7	10,195	14,885
Quarry No. 1	13,117	14,962

There does not appear any marked variation in the calorific value in an easterly direction viz. from Swang to Dhori, the average being about 15,000 B.th.u./lb (d.a.f.). The middle portion of the seam in the Bokaro colliery shows low calorific value as its ash content is comparatively higher. Following the Indian Coal Grading Board specifications (see Fox, 1934, p. 169) a good portion of coal of the Kargali seam may be regarded as belonging to 'Grade I' category.

Coking Characters

Coke Button

The study of coke buttons left after the volatile matter test is of considerable interest as it gives sufficiently accurate information regarding the coking properties of coal and its swelling and agglomeration power. Gilmor *et al.* (see Mott, 1942, p. 86) were the first to deal with this subject and they introduced the following five gradings of coke buttons obtained by the usual laboratory tests:-

1. Non-agglomerating (Non-coking)
2. Agglomerating
3. Poor coking
4. Fair coking
5. Good coking

TABLE NO. 4: STANDARD GRADING OF COKE BUTTONS FROM VOLATILE MATTER DETERMINATIONS. (After Barkley and Burdick)

Designation		Appearance of residue from standard method for determination of volatile matter in coal
Class	Group	
Non-agglomerating. (Button shows no swelling or cell structure and will not support a 500-g. weight without pulverising).	NA-(non-agglomerate)	NAa - Non-coherent residue. NAb - Coke button shows no swelling or cell structure and after careful removal from the crucible will pulverise under a weight of 500 g. carefully lowered on button.
Agglomerating. (Button shows swelling or cell structure or will support a 500-g. weight without pulverising).	A-(agglomerate). Button dull black, sintered, shows no swelling or cell structure. Will support a 500-g. weight without pulverising).	Aw - (weak agglomerate). Buttons come out of crucible in more than one piece. Af - (firm agglomerate). Buttons come out of crucible in one piece.
	C-(caking). Button shows swelling or cell structure.	Cp - (poor caking). Button shows slight swelling with small cells. Has slight grey lustre. Cf - (fair caking). Button shows medium swelling and good cell structure. Button has characteristic metallic lustre. Cg - (good caking). Button shows strong swelling and pronounced cell structure, with numerous large cells and cavities. Button has characteristic metallic lustre.

These authors used the terms 'Aw' and 'Af' for denoting weakly agglomerating and fairly agglomerating coke buttons respectively. The use of the term 'coking' instead of 'caking' by these authors was based on the fact that the coals had been coked in a 2 ton experimental coke oven. Barkley and Burdick (see Mott, 1942, p. 87) preferred to use the term 'caking' and prepared a modified classification of coke buttons as shown in Table No. 4.

Mott (1942) and Fieldner (1943) agree with this classification and it is acceptable to the U.S. Bureau of Mines also. In order to avoid the increasing confusion of the term caking, Mott has suggested the use of the term 'weakly-swelling' and 'strongly-swelling' in place of the terms 'weakly-caking' and 'strongly-caking'.

In the light of the above classification, Table No. 5 summarizes the agglomerating and swelling qualities of coke buttons of the Kargali seam in the different collieries.

TABLE NO. 5: DISTRIBUTION OF COKE BUTTON TYPES IN THE KARGALI SEAM.

Colliery	No. of samples analysed	NA_b	A_w	A_f	C_p	C_f	C_g
Swang, Quarry No. 2	6	-	1	2	1	2	-
Bokaro, Quarry No. 7	34	-	7	11	6	10	-
Bokaro, Quarry No. 2	7	-	5	-	-	2	-
Kargali, Quarry No.1	10	-	2	2	2	4	-
Kargali, Quarry No.2	9	-	-	5	2	2	-
Kargali, Quarry No.3	10	-	1	5	1	3	-
Dhori, Incline No. 7	2	2	-	-	-	-	-
Dhori, Quarry No. 1	2	-	-	1	-	1	-
Total	80	2	16	26	12	24	-
Per cent		2.5	20.0	32.5	15.0	30.0	-

There seems a general uniformity in the caking and agglomerating properties of the Kargali seam from its western to eastern end viz. from Swang to Dhori. It is evident from the above Table that 77 per cent of coke button types indicate a good caking coal, while 20 per cent show poorly caking coal. The remaining 3 per cent represent non-caking coal.

It has been observed that fairly swelling type of coke buttons (Cf) with good cell structure and metallic lustre are obtained from coals having an average volatile matter of 34.9 per cent. As the volatile contents decrease, the agglomerating power diminishes. While studying the coking properties and their regional variation, Teichmüllers (1958) have plotted the isovols of vitrain in the Reinkohle, Germany and observed that well swollen coke buttons are obtained from specimens having a volatile content of about 20 per cent.

Caking Index

Caking index was determined according to the standard Gray-Campredon method which is the same as adopted by the Fuel Research Institute and Coal Blending & Carbonization Research Laboratory (Report No. 2, Fuel Research Committee, 1948). These determinations were made on 25 samples and the results are included in Table No. 2. The average value of caking indices in the eight quarries is given below:-

Colliery	Caking Index
SWANG	
Quarry No. 2	20
BOKARO	
Quarry No. 7	18
Quarry No. 2	20
KARGALI	
Quarry No. 1	18
Quarry No. 2	17
Quarry No. 3	19
DHORI	
Incline No.7	18
Quarry No. 1	18

The average caking index varies from 17 to 20. The upper limit for a good coking coal is 15 (see Report No. 2, Fuel Research Committee, loc. cit., p. 14), so that coals of the Kargali seam are good coking coals.

Swelling Power

The swelling power of a coal is closely related to its coking characters (Slater, 1927; Spooner and Mott, 1937; Mott, 1942; Berkowitz, 1950). Opinions differ as to which method should be adopted in the laboratory for determining the swelling power, because the properties of coke obtained by laboratory methods are different as compared to those obtained in coke ovens. Both Slater and Mott favour the use of B.S. crucible swelling test for the determination of swelling index in the laboratory. Slater (loc. cit., p. 84), however, points out that "the swelling of the coke in the laboratory test cannot be accepted alone as an absolute criterion of coking quality of coal in actual practice, when coals from different coalfields are under examination".

The method followed in the present investigation is the B.S. crucible swelling test and the conclusions arrived at are tentative.

Out of 80 samples analysed, the Swelling No. was determined for 47 specimens and the results are recorded in Table No. 2. The Swelling No. varies from 2 to 7½, but generally it is 4. It is clear from the Table that certain horizons of the Kargali seam show non-swelling coals which are either fairly to strongly agglomerating without fissures, or poorly agglomerating and fissured to non-agglomerating. The average Swelling No. in the different collieries is as follows:-

Colliery		B.S. Swelling No.
SWANG:	Quarry No. 2	5
BOKARO:	Quarry No. 7	4½
	Quarry No. 2	3½
KARGALI:	Quarry No. 1	3½
	Quarry No. 2	4
	Quarry No. 3	4
DHORI:	Incline No.7	3
	Quarry No. 1	3

Coals with Swelling No. of about 4 are generally regarded as good coking coals provided the heat of wetting is low (Carbonization Potentialities of certain Madhya Pradesh coals, F.R.I. Publication, 1954, p. 15).

It is well known that the swelling power of coal decreases with increasing ash content (Spooner and Mott, 1937, p. 105; Ganju, 1955, p. 33). It is observed so in the present investigation also and Fig. 7 shows this relationship between these two constituents. A direct relationship, however, is observed between the swelling power and volatile contents (d.a.f.) as shown in Fig. 8. Berkowitz (1950, p. 140) derived a similar relationship between Swelling No. and volatile matter for coals of different rank.

The studies of coke button types, caking index and swelling power suggest that coals of the Kargali seam would generally yield a good coke in actual practice.

After taking into consideration the chemical characters discussed above, it is possible to say that most of the Kargali coals belong to B_2 (medium volatile-caking) and B_3 (high volatile-caking) groups of the ISI classification (General Classification of Indian Coals, Indian Standard Institution, 1955, p. 10).

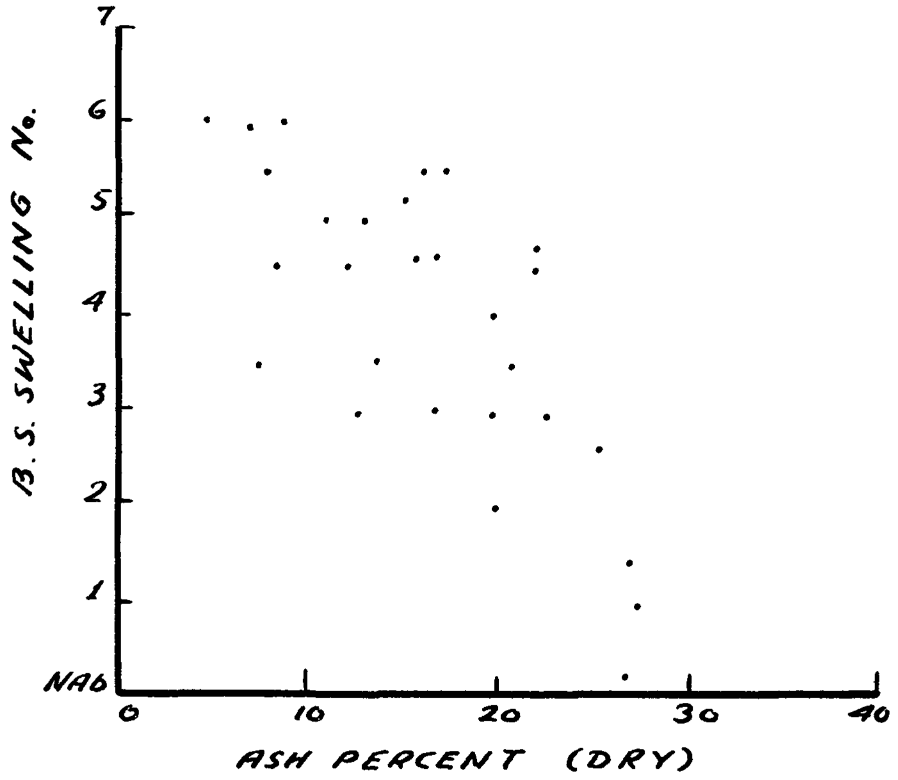

FIG. 7. ASH AND B.S. SWELLING NO. RELATIONSHIP IN THE KARGALI COALS.

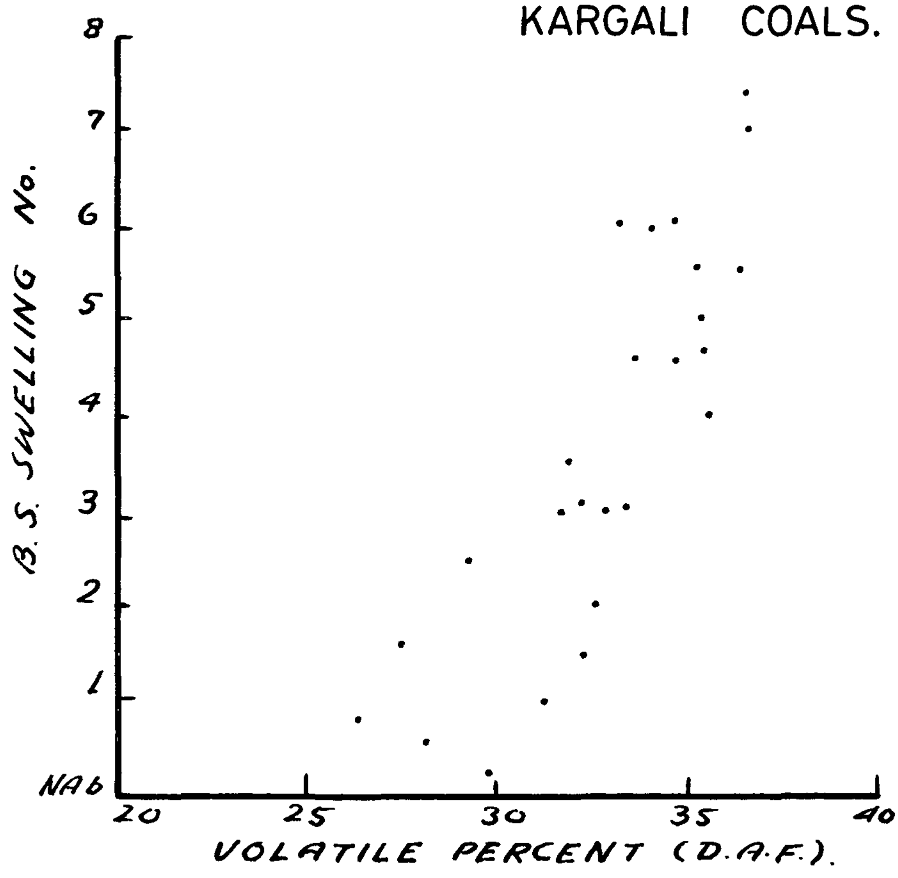

FIG. 8. VOLATILE AND B.S. SWELLING RELATIONSHIP IN THE KARGALI COALS.

Petrographic Analysis

Many workers have shown that the nature of petrological constituents has an important bearing on the problems of carbonization, burning and cleaning of coal (Jefferey, 1925; Pieters and Koopmans 1932; Hoffman and Jenker, 1933; Marshall, 1943, 1958; Brown, 1957). Coal is an assemblage of microlithotypes which comprise of macerals like vitrinite, fusinite, exinite, micrinite etc. in varying proportion. These components behave differently on burning and chemical treatment. It is not only the specific properties of coal macerals which govern the properties of coal, the mode of their distribution and their relative abundance are equally important. An attempt has been made here to correlate the results of petrographic analysis with the results of chemical examination.

Thin sections of 21 samples covering four collieries of Swang, Bokaro, Kargali and Dhori were analysed petrographically using Leitz six spindle integrating stage. The samples from which thin sections were made were also analysed chemically. The results of petrographic analysis are shown in Table No. 6 and those of chemical analysis in Table No. 2. It may be pointed out that the petrographic analysis is not representative of a particular colliery or of any section of the seam.

Vitrinite varies from 52.1 to 88.8 per cent in the coals examined. Spores are sparsely distributed and are restricted to coals of the Swang colliery. These are generally absent in coals of the eastern collieries

TABLE NO. 6: PETROGRAPHIC ANALYSES OF THE KARGALI SEAM (PER CENT)

S.No.	Sample No.	Colliery	Vitrinite	Durain	Spores	Siderite	Ash
1.	S/1	Swang	76.7	21.4	0.58	0.05	1.18
2.	S/2	Swang	89.9	8.45	0.07	0.57	1.00
3.	S/6	Swang	66.2	32.9	0.12	0.24	0.48
4.	S/8	Swang	76.1	21.5	0.23	0.92	1.32
5.	KB7/3	Bokaro, Quarry No. 7	74.3	24.2	0.84	0.00	0.61
6.	KB7/47	Bokaro, Quarry No. 7	80.7	28.4	0.00	0.04	0.84
7.	KB7/75	Bokaro, Quarry No. 7	85.5	13.6	0.00	0.00	0.84
8.	KB7/90	Bokaro, Quarry No. 7	88.8	10.4	0.06	0.00	0.70
9.	KB2/12	Bokaro, Quarry No. 2	81.9	13.9	0.15	0.59	3.44
10.	KK1/3	Kargali, Quarry No. 1	80.8	18.1	0.02	0.44	0.60
11.	KK1/6	Kargali, Quarry No. 1	52.1	44.5	0.00	1.71	1.62

TABLE NO. 6: PETROGRAPHIC ANALYSES OF THE KARGALI SEAM (CONTINUED).
(PER CENT)

S.No.	Sample No.	Colliery	Vitrinite	Durain	Spores	Siderite	Ash
12.	KK1/9	Kargali, Quarry No. 1	72.8	25.8	0.00	0.25	1.12
13.	KK1/12	Kargali, Quarry No. 1	67.1	30.7	0.14	0.10	1.23
14.	KK2/6	Kargali, Quarry No. 2	81.5	11.2	0.15	6.54	5.11
15.	KK2/11	Kargali, Quarry No. 2	83.7	7.6	0.05	7.73	1.13
16.	KK2/22	Kargali, Quarry No. 2	67.90	30.8	0.01	1.39	0.31
17.	KK2/28	Kargali, Quarry No. 2	60.20	34.9	0.00	3.34	1.55
18.	KK3/1	Kargali, Quarry No. 3	84.5	13.6	0.00	0.07	1.45
19.	KK3/9	Kargali, Quarry No. 3	81.4	15.5	0.00	0.83	2.24
20.	KK3/12	Kargali, Quarry No. 3	75.9	21.8	0.00	0.81	1.47
21.	KQ1/5	Dhori, Quarry No. 1	64.2	32.9	0.00	2.09	0.92

and none have been observed in those of the Dhori colliery. Mineral matter is dominant in coals of the Kargali and Dhori collieries.

For coals of the same rank an increase in the proportion of vitrinite may in part account for the relative increase of their swelling and caking power and calorific value. This is clearly observed in Fig. 9.

Jefferey (1925) found that the formation of coke is in direct proportion to the amount of woody material or anthraxylon. Pieters and Koopmans (1932) agreed with Jefferey's findings and they showed experimentally that while anthraxylon cokes, attritus does not. Fox (1931, p. 185) also observed that the swelling power increases with an increase in vitrinite. Broche and Schmitz (1933) are of the view that bright coal on coking gives a cemented hard coke, while dull coal gives a weakly-sintered non-cemented coke. Recently while discussing the coking properties of bright constituents, Feigellman (1955) and Papova and Permitina (1955) have observed that a bright complex-banded coal has the best caking properties.

An increase in the proportion of durain, on the other hand, lowers the swelling and caking power. This fact is clear in Fig. 10 where the swelling number decreases rapidly when the proportion of durain is above 25 per cent. Spooner and Mott (1937, p. 102) and Mott (1942, p. 84) agree with the view that the swelling power is lowered by an increase in the amount of durain. Mainze and Schwagmann (1948) and Parks <u>et al</u>. (1957) are also of the opinion that swelling is produced

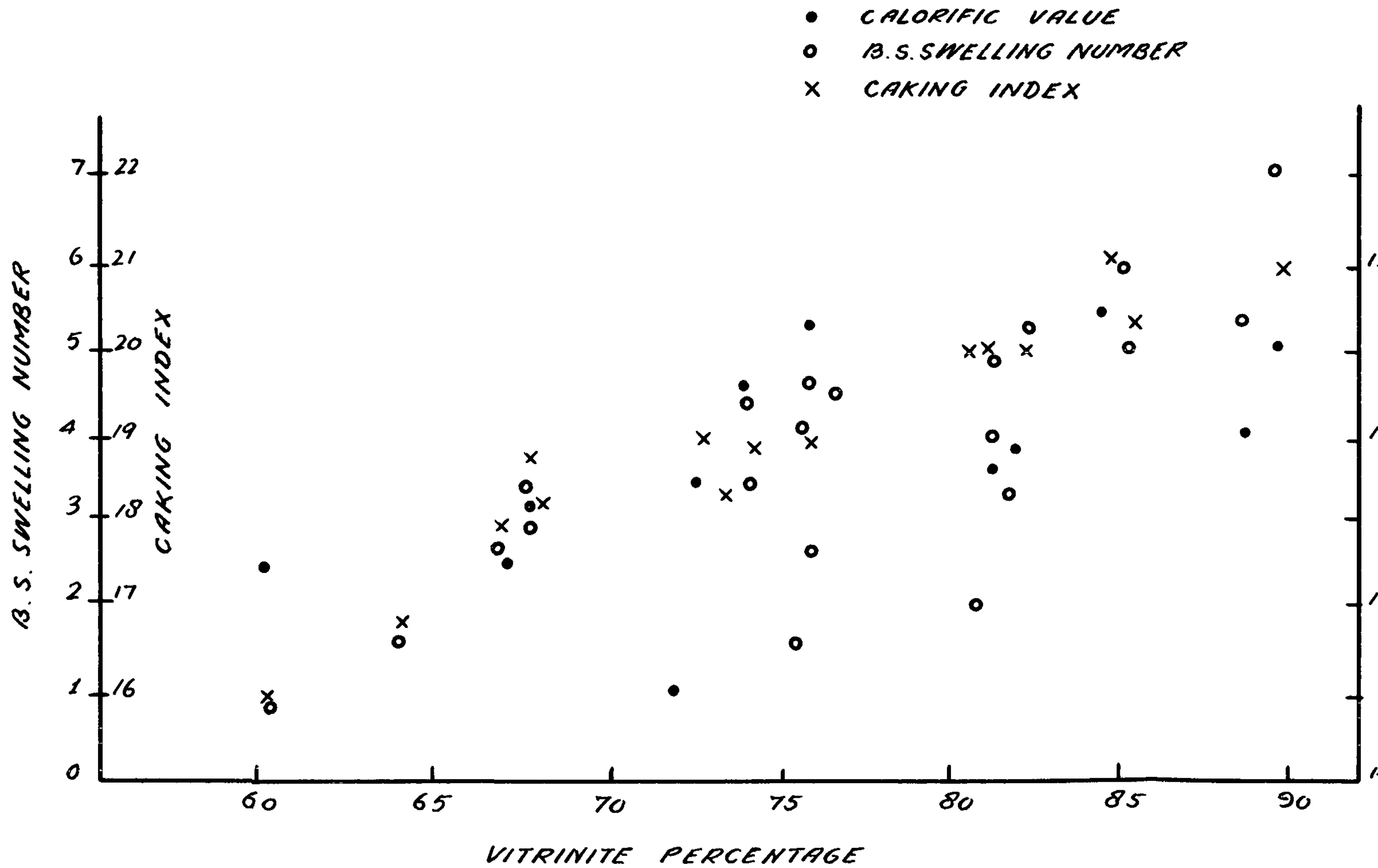

FIG. 9. RELATIONSHIP OF COKING CHARACTERS AND CALORIFIC VALUE VITRINITE PERCENTAGE IN COALS OF THE KARGALI SEAM.

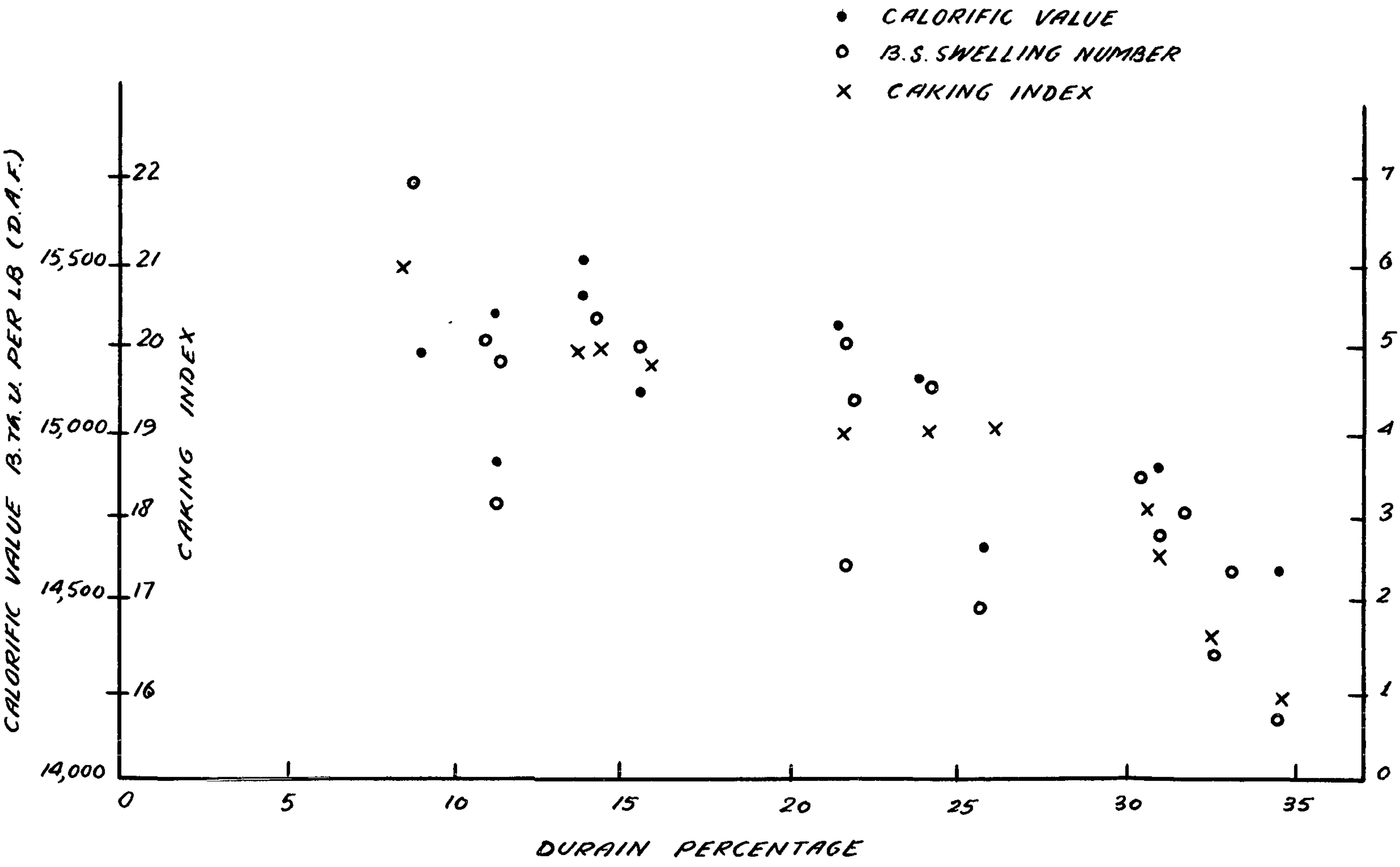

FIG. 10. RELATIONSHIP OF COKING CHARACTERS AND CALORIFIC VA
DURAIN PERCENTAGE IN COALS OF THE KARGALI SEAM.

from the bright constituents, while the dull ingredients cause a considerable shrinkage of coke. Spooner (1951, p. 197), however, goes a step further and observes that "the presence of upto 30 per cent durain or fusain does not reduce the swelling power of bright coal .... and only when the percentage of bright coal is less than 70 per cent is the swelling power much affected".

THE KARO MEASURES

As mentioned earlier, the Top and Bottom Karo seams are the two main seams of the Karo measures. The seam which outcrops to the east of the Teesri nala fault has been designated as the Eastern Karo seam (see p. 22). These seams are being worked in nine collieries as follows:-

Colliery		Seam
1. Dhori, Karo Plot 'A'	...	Bottom Karo
2. Khas Dhori, Quarry No. 2	...	" "
3. Khas Dhori, Quarry No. 3	...	Top Karo
4. Pichri	...	" "
5. East Bokaro	...	" "
6. Turio	...	Eastern Karo
7. Selected Kargali	...	" "
8. Kalyani Selected Kargali	...	" "
9. Selected Dhori	...	" "

Chemical Analysis

25 samples of the Bottom Karo, Top Karo and Eastern Karo seams were analysed chemically. The distribution of the samples is shown in Figs. 11 & 12 and the results of analysis are recorded in Table No. 7.

The variation in the different constituents is as follows:-

Moisture

The moisture content is low, the average value being about 0.3 per cent. The low moisture content may be due to the fact that the Karo measures occur at the lowest stratigraphical horizon in the Barakars.

Ash

The ash content varies widely from 9.8 to 29.9 per cent. On the whole the coals contain high ash and this is true especially for the Karo measures lying west of the Teesri nala fault. In this area the ash content varies from 14.3 to 29.9 per cent, the average value being 20.0 per cent. A marked reduction in the ash content is observed in the Eastern Karo seam which shows an ash content of 9.8 to 20.1 per cent with an average value of 15.2 per cent. The values of ash content were also calculated according to Fermor's formula viz. $a = 100(g-k)$, where a stands for ash content, g for specific gravity and k is the

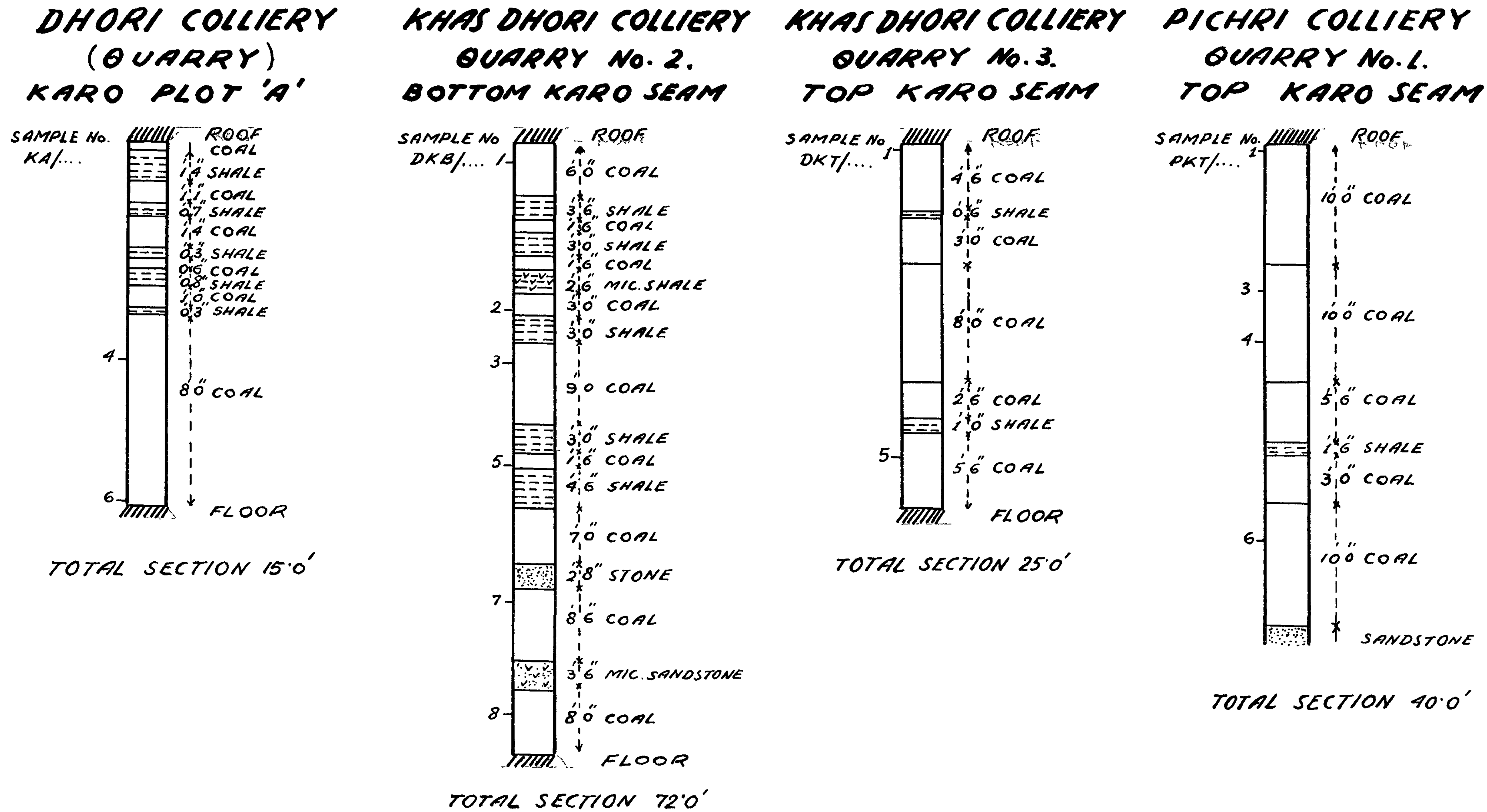

FIG. 11. SECTION OF THE TOP AND BOTTOM KARO SEAMS.

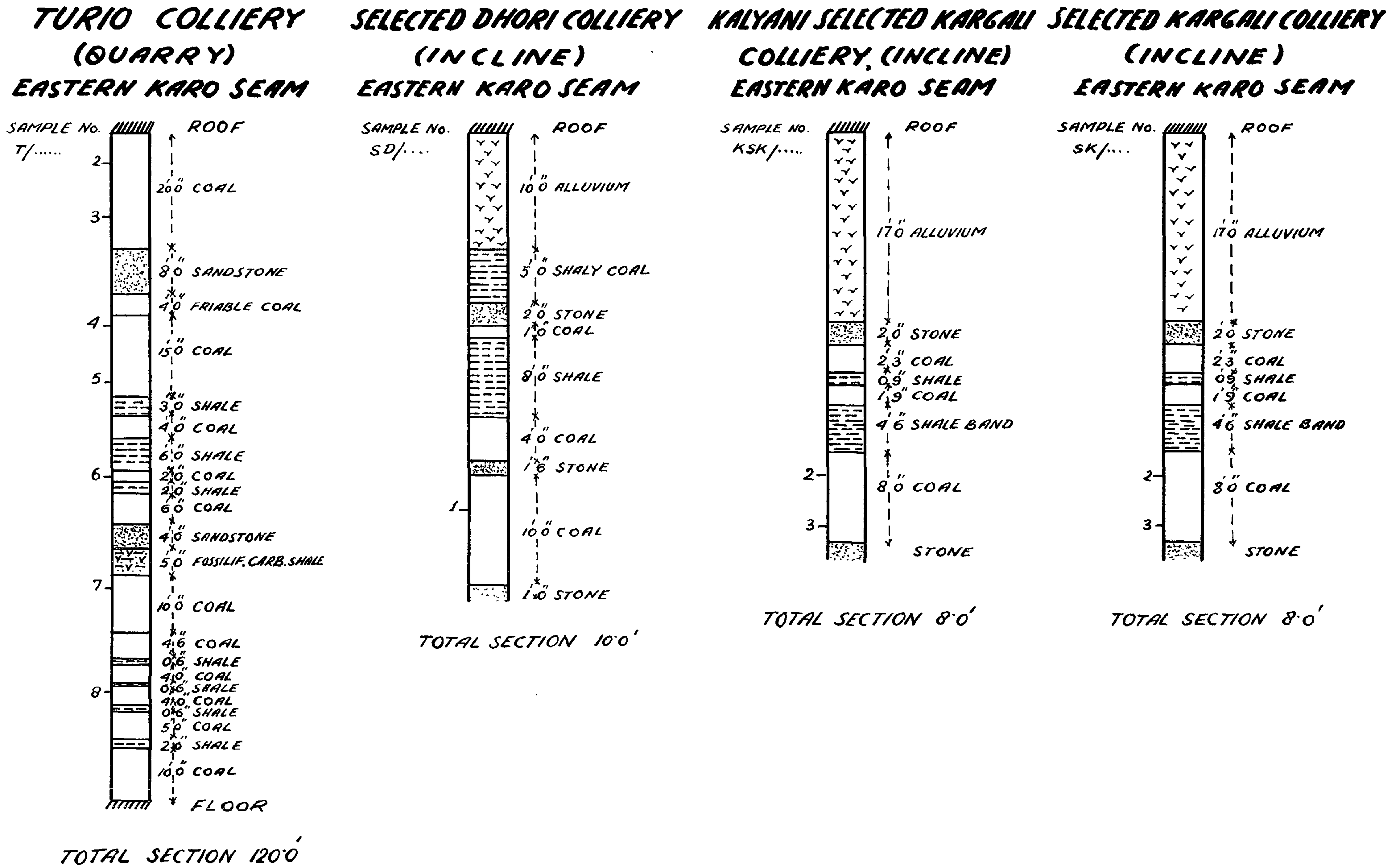

FIG. 12. SECTION OF THE EASTERN KARO SEAM.

TABLE NO. 7: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARO MEASURE COALS.

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B.Th.U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
1.	KA4	0.3	17.1	17.7	64.9	21.4	78.6	12,575	15,224	Pink	Af	Strong, non-swoll.	18	NS	Dhori Coll., Karo plot 'A'.
2.	KA6	0.3	20.0	18.7	61.0	23.4	76.6	-	-	Greyish white	Aw	Black, non-swoll., fiss.	-	NS	-do-
3.	DKB1	0.2	23.4	19.8	58.6	25.9	79.1	11,002	14,400	Pinkish white	Aw	Strong, two broken piece	16	1	Khas Dhori, Quarry No. 4.
4.	DKB2	0.3	16.3	21.0	62.4	25.9	74.1	-	-	Greyish white	Af-Cp	Slightly swoll., lustr. white.	18	1½	-do-
5.	DKB3	0.2	17.2	19.2	63.4	23.2	76.8	-	-	Creamish	Aw	Greyish blue, strongly swoll., broken.	-	1½	-do-
6.	DKB5	0.3	14.3	21.4	64.0	25.1	74.9	-	-	Creamish white	Cf	Slightly swoll.	-	3	-do-
7.	DKB7	0.3	22.7	17.9	57.1	23.3	76.7	11,714	15,213	White	Aw	Strongly swoll., broken pieces, lustr. black.	17	-	-do-
8.	DKB8	0.2	18.8	18.2	62.8	22.4	77.6	-	-	Creamish	Aw	-do-	-	NS	Khas Dhori, Quarry No. 3.
9.	DKT1	0.3	22.9	22.5	54.3	29.3	70.7	-	-	Pinkish white	Af	Strongly aggl.	18	-	-do-
10.	DKT5	0.3	20.1	22.9	56.7	28.8	71.2	11,684	14,921	Greyish white	Af	Slightly swoll., slightly porous.	-	3	Pichri Coll., Quarry No. 2.
11.	PKT1	0.4	18.1	24.6	56.9	30.5	69.5	-	-	Pinkish	Cf	Fairly swoll., greyish white.	-	2½	-do-
12.	PKT3	0.3	29.8	22.5	47.4	32.2	67.8	9,953	14,339	Creamish	Af	Strongly aggl., non-swoll.	16	-	-do-
13.	PKT4	0.2	18.2	29.0	57.6	29.4	70.6	11,950	14,644	Pinkish white	Cg	Slightly swoll., with cell structure.	-	1	-do-
14.	PKT6	0.2	24.1	19.6	56.1	25.9	74.1	-	-	Creamish	Aw	Strong, broken piece, black.	-	-	-do-

TABLE NO. 7: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KARO MEASURE COALS (CONTINUED).

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B.Th.U./lb		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Vola-tile	Fixed Carbon	Volatile	Fixed Carbon	As deter-mined	On d.a.f. basis						
15.	T2	0.3	14.3	24.8	60.6	29.0	71.0	12,788	14,974	Pinkish white	Cg	Strongly swoll., metall. lustr., porous.	19	5	Turio Coll., eastern Karo seam.
16.	T3	0.3	11.9	22.0	65.8	25.6	74.4	-	-	Greyish white	Cf	Fairly swoll., silvery white, porous.	-	4½	-do-
17.	T4	0.4	15.8	21.9	61.9	26.1	73.9	-	-	-do-	Cf	Fairly swoll., silvery white, porous.	-	4½	-do-
18.	T5	0.2	15.0	20.5	64.3	24.2	75.8	-	-	-do-	Af	Strongly aggl., non-fiss.	17	2	-do-
19.	T6	0.2	20.0	17.8	62.0	22.5	77.5	-	-	Pinkish white	Af	-do-	-	-	-do-
20.	T7	0.3	16.6	22.5	60.6	27.7	72.3	-	-	Light slaty	Cf	Fairly swoll., slightly porous.	19	4½	-do-
21.	T8	0.3	18.8	21.5	69.4	26.6	73.4	12,433	15,368	Greyish white	Cf	-do-	18	4	-do-
22.	SK2	0.3	12.0	19.1	68.6	21.7	78.3	13,446	15,332	Creamish	Cf	Fairly swoll., silvery white.	18	4	Selected Kargali
23.	SD1	0.3	20.1	16.5	63.1	20.7	79.3	-	-	Pink	Af	Grey, broken piece.	16	-	Selected Dhori
24.	KSK2	0.2	9.8	19.1	70.1	21.2	78.8	14,010	15,566	Greyish white	Aw	Non-swoll., strong.	18	2½	Kalyani Selected Kargali.
25.	KSK3	0.3	12.5	18.9	68.3	21.6	78.4	-	-	White	Aw	Non-swoll., grey, fiss.	-	-	-do-

specific gravity constant of pure coal (Fermor, 1928). It is interesting to note that the calculated values of the ash (Casshyap, 1960a) as given in Table No. 8 are generally very near to those obtained by actual analysis.

Volatile Matter

The Top Karo and Bottom Karo can be differentiated clearly on the basis of their volatile contents. While in the Top Karo volatiles (on d.a.f. basis) vary from 25.9 to 32.2 per cent, in the Bottom Karo the range is from 21.4 to 25.9 per cent. Thus the Top Karo coals are medium volatile and those of the Bottom Karo are low to medium volatile. Coals of the Eastern Karo seem show a volatile range of 22.5 to 29.0 per cent.

Carbon, Hydrogen and Sulphur

These determinations were made on six samples and the results appear in Table No. 9.

TABLE NO. 9: RESULTS OF THE ULTIMATE ANALYSIS OF KARO MEASURE COALS.

S.No.	Sample No.	as calculated (per cent)			dry ash free (per cent)		
		H	C	S	H	C	S
1.	KA/4	3.95	74.85	0.25	4.77	90.34	0.30
2.	DKB/1	3.80	66.63	0.29	4.97	87.16	0.38
3.	DKB/7	3.72	68.01	0.28	4.82	88.12	0.36
4.	T/2	4.42	47.04	0.68	5.16	86.43	0.70
5.	SK/2	4.29	79.11	0.38	4.88	89.91	0.43
6.	KSK/2	4.11	81.90	0.30	4.56	90.04	0.41

TABLE NO. 8: RESULTS OF SPECIFIC GRAVITY AND ASH CONTENTS OF KARO MEASURE COALS.

(Specific gravity of pure coal or the value of 'K' = 1.29)

S.No.	Sample No.	Seam	Colliery	Horizon	Specific gravity	Ash contents $a = 100(g-k)$ per cent	Remark
1.	Kc2	Top Karo	Dhori, Karo Plot No.C.	1 ft. from Top	1.56	27	
2.	Kc3	" "	" "	3 ft. " "	1.60	31	
3.	Kc4	" "	" "	5 ft. " "	1.67	38	Siderite grains fairly prominent.
4.	Kc5	" "	" "	6 ft. " "	1.53	24	
5.	Kc6	" "	" "	7 ft. " "	1.44	15	
6.	KA1	" "	Dhori, Karo Plot No.A.	Top	1.48	19	
7.	KA2	" "	" "	2 ft. " "	1.55	26	
8.	KA3	" "	" "	3. 5 ft." "	1.56	27	
9.	KA4	" "	" "	9 ft. " "	1.60	31.5	
10.	KA5	" "	" "	12 ft. " "	1.47	18	
11.	KA6	" "	" "	15 ft. " "	1.36	9	
12.	DKB1	Bottom Karo	Khas Dhori, Quarry No. 2.	1 ft. " "	1.48	19	
13.	DKB2	" "	" "	17 ft. " "	1.42	13	
14.	DKB3	" "	" "	22 ft. " "	1.46	17	
15.	DKB4	" "	" "	27 ft. " "	1.44	15	

TABLE NO. 8: RESULTS OF SPECIFIC GRAVITY AND ASH CONTENTS OF KARO MEASURE COALS (CONTINUED).

(Specific gravity of pure coal or the value of 'K' = 1.29)

S.No.	Sample No.	Seam	Colliery	Horizon	Specific gravity	Ash contents a = 100(g-k) per cent	Remark
16.	DKB5	Bottom Karo	Khas Dhori, Quarry No. 2.	32 ft. from Top	1.44	15	
17.	DKB6	" "	" "	45 ft. " "	1.46	17	
18.	DKB7	" "	" "	55 ft. " "	1.37	8	Rich in vitrain
19.	DKB8	" "	" "	69 ft. " "	1.50	23	
20.	DKT1	Top Karo	Khas Dhori, Quarry No. 3.	Top	1.51	22	
21.	DKT2	" "	" "	6 ft. " "	1.53	24	
22.	DKT3	" "	" "	11 ft. " "	1.54	25	
23.	DKT4	" "	" "	16 ft. " "	1.31	6	Highly vitrainy
24.	DKT5	" "	" "	22 ft. " "	1.42	13	
25.	PKT1	" "	Pichri, Quarry No. 1.	Top	1.43	14	
26.	PKT2	" "	" "	6 ft. " "	..	..	
27.	PKT3	" "	" "	12 ft. " "	1.69	40	Shaly durain
28.	PKT4	" "	" "	18 ft. " "	1.43	14	
29.	PKT5	" "	" "	30 ft. " "	1.50	21	
30.	PKT6	" "	" "	33 ft. " "	1.49	20	

On dry-ash-free basis carbon varies from 86.43 to 90.34 per cent, hydrogen from 4.56 to 5.16 per cent and sulphur from 0.30 to 0.70 per cent.

Calorific Value

Calorific value determinations were made on 10 specimens and the results are given in Table No. 7. For coals of the Top Karo the calorific values (d.a.f.) range from 14,339 to 14,921 B.th.u./lb, while in the Bottom Karo coals the variation is from 14,400 to 15,224. The coals of the Eastern Karo seam show higher calorific values varying from 14,974 to 15,566.

Coking Characters

Coke Button

There appears a distinct variation in the nature of coke buttons. While the buttons of the Bottom Karo are generally weakly to fairly agglomerating (Aw to Af), those of the Top Karo are fairly agglomerating (Af) to fairly swelling (Cf) and in a few cases good swelling (Cg) also. The Eastern Karo coals yield generally fairly agglomerating (Af) to fairly swelling (Cf) type of coke buttons and are therefore better caking as compared to those of the Bottom Karo seam. Six types of coke buttons varying from good swelling (Cg) to non-agglomerating (NAb) are shown in Fig. 13.

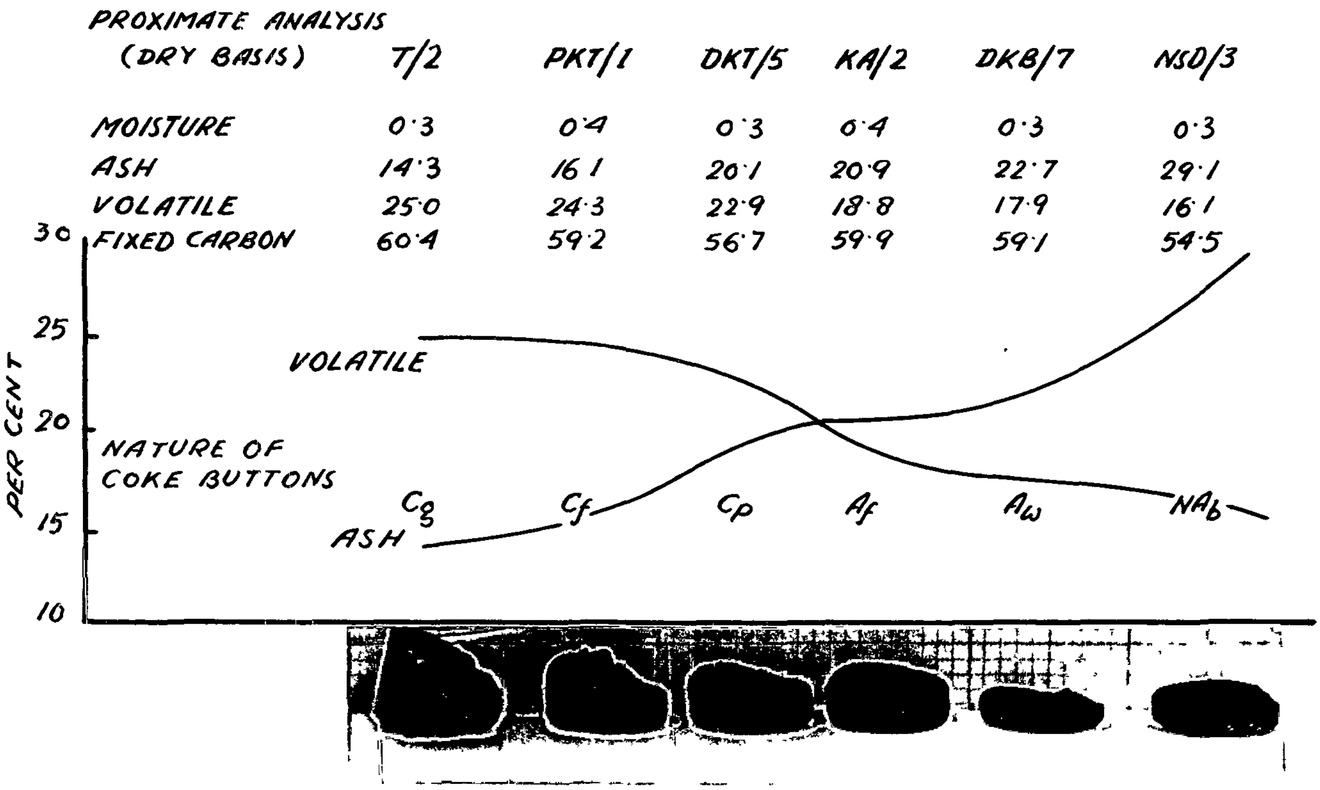

FIG. 13. VARIATION IN THE NATURE OF COKE BUTTONS WITH ASH AND VOLATILE PERCENTAGE IN COALS OF THE KARO MEASURES.

<u>Caking Index</u>

The caking index for 13 specimens ranges from 16 to 19 as shown in Table No. 7. The highest value of 19 has been recorded in the specimen from the Eastern Karo seam.

<u>Swelling Power</u>

The Swelling No. determinations were made on 14 specimens and the values are recorded in Table No. 7. The Swelling No. ranges from 1 to 5 and shows a direct relationship with the volatile content as in the Kargali seam.

It is clear that the coals of the Bottom Karo seam are poorly to non-coking. The coals of the Top Karo and Eastern Karo seams, on the other hand, are generally good coking coals, but the high ash content of the Top Karo coals would make these unsuitable for metallurgical and industrial purposes. They can be utilized in industry on being suitably cleaned.

<u>Petrographic Analysis</u>

Eight specimens were analysed petrographically. The results of petrographic analysis appear in Table No. 10, while those of chemical analysis are given in Table No. 7.

In contrast to the Kargali coals, the coals of the Karo measures contain a low percentage of vitrinite ranging from 16.5 to 45.8. Fusinite

TABLE NO. 10: PETROGRAPHIC ANALYSIS OF THE KARO MEASURE COALS

	Colliery	Sample No.	Vitrinite (per cent)	Durain (per cent)	Fusinite (per cent)	Mineral Matter (per cent)
1.	Khas Dhori, Quarry No. 2	DKB/1	16.5	49.4	20.6	13.4
2.	Khas Dhori, Quarry No. 2	DKB/7	24.7	42.3	17.3	15.7
3.	Khas Dhori, Quarry No. 3	DKT/1	27.8	41.2	10.6	20.4
4.	Khas Dhori, Quarry No. 3	DKT/5	24.8	43.1	9.7	22.4
5.	Pichri	PKT/3	17.4	59.7	20.9	2.0
6.	Pichri	PKT/4	16.7	58.8	21.9	2.46
7.	Turio	T/2	45.8	35.5	8.4	12.3
8.	Turio	T/8	43.4	30.0	15.9	10.1

and mineral matter are fairly abundant, their average values being 15.7 per cent and 12.6 per cent respectively. Durain varies from 30.6 to 59.7 per cent.

Gray-King Low Temperature Carbonization Assay

In some instances the results of proximate and ultimate analyses of coal have to be supplemented by a laboratory test in which a detailed examination of the behaviour of coal on carbonization is made. Such a test provides useful data regarding the yield and quality of coke, tar, liquor and gas. Two types of assays have been developed. One is the low temperature carbonization assay performed at 600°C and the other, known as the high temperature assay, is carried at 900°C. The method used in the Gray-King assay tests at 600°C (LTC) is the same as adopted by the Fuel Research Station, London, vide report No. 44 of 1940 and followed by the Fuel Research Institute of India (see 'Metallurgical Cokes from Raniganj Coals', Fuel Research Institute Publication, 1955).

The Gray-King carbonization tests were made on six samples and the results are reported in Table No. 11.

The yield of coke (on dry coal) varies from 16.04 cwt. to 17.01 cwt. per ton, the maximum being in the Kalyani Selected colliery (KSK/2), working the Eastern Karo seam. The yield of tar ranges from 13.86 to 21.19 gallons per ton. The Top Karo seam in the Pichri colliery (PKT/3) yielded the maximum tar. The gas yield varies from 2,568 to 3,354 cu. ft./ton, the maximum being from the coals of the Pichri colliery (PKT/3). On the whole the coals of the Top Karo seam yield more tar and gas as compared to those of the Bottom and Eastern Karo seams.

TABLE NO. 11: GRAY-KING LOW TEMPERATURE CARBONIZATION ASSAY OF THE KARO MEASURE COALS.

S.No.	Sample No.	Yield per 100 gms. of dry coal				Yield per ton of dry coal				Behaviour on distillation		Character of Coke	Colliery
		Coke (gms)	Tar (gms)	Liquor (gms)	Gas in c.cu.at S.T.P.	Coke (cwt.)	Tar (gals.)	Liquor (gals.)	Gas in cu. ft. at S.T.P.	First appearance of oil at °C	First appearance of gas at °C		
1.	KSK2	85.05	6.19	2.38	6,981	17.01	13.86	5.33	2,586	390	415	G	Kalyani Selected Kargali.
2.	T7	82.00	8.65	3.23	9,351	16.40	19.37	7.23	3,348	340	400	G	Turio
3.	DKB1	83.43	7.54	2.96	8,080	16.68	16.88	6.63	2,892	350	385	F	Khas Dhori, Quarry No. 2.
4.	PKT3	80.22	9.46	3.34	9,370	16.04	21.19	7.48	3,354	380	395	G	Pichri, Quarry N
5.	DKT1	80.87	9.28	3.05	9,330	16.17	20.78	6.83	3,335	365	375	G	Khas Dhori, Quarry No. 4.
6.	DKT5	81.13	9.07	2.55	9,218	16.22	20.31	5.71	3,301	347	364	E	-do-

In four out of six cases the coke left was of 'G' type, indicating hard, standard coke having the same volume as the original coal. One sample (DKB/1) gave 'F' type coke, indicating slightly shrunken and hard coke and the last sample (DKT/5) yielded 'E' type coke, viz. shrunken, fissured and hard coke. Fig. 14 shows coke residues 'G' and 'F' of sample Nos. KSK/2 and DKB/1.

Although the present study does not go far enough in determining the exact behaviour of these coals on distillation, it nevertheless appears to be the first attempt in this direction.

Grindability Tests on the Karo Measure Coals

The use of pulverized fuel in boilers is becoming increasingly popular with the rapid industrialization of the country so that special attention is being paid these days towards the grindability character of coals. As all kinds of coal cannot be subjected to pulverization, the measurement of grindability is an essential factor to be considered while selecting a coal for pulverization.

Calcott (1956) was probably the first to carry out a concrete study of coal grindability. He surveyed grindability of the British coals and calculated that the Index is a first-order measure of the strength of coal. Hawksley (see Calcott, loc. cit., p. 207), who carried out a preliminary investigation on the grindabilities of British

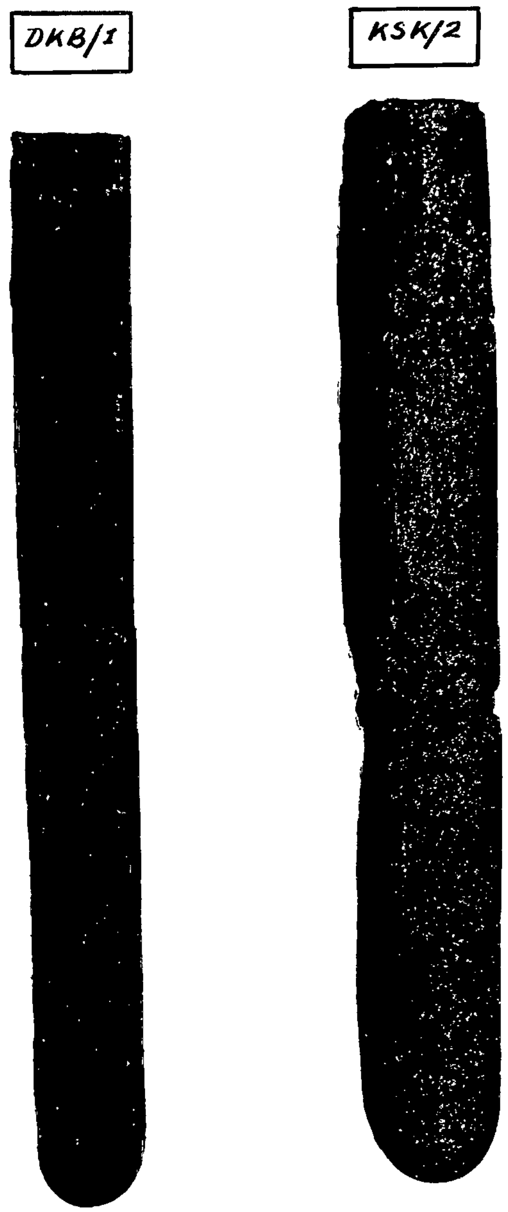

FIG. 14. GRAY-KING COKE TYPES FROM THE BOTTOM KARO (DKB/1) AND EASTERN KARO (KSK/2) SEAMS.

bright coals arrived at similar conclusions. Fitton _et al_. (1957) extended the studies on the grindability of British coals and determined the Indices on two laboratory machines. They also obtained a closer relationship between grindability and volatile matter, ash, carbon and hydrogen contents.

The only substantial work on grindability of Indian coals is by Ghosal _et al_. (1958). These authors determined the grindability characters of various Indian coals and confirmed the earlier established relationship (Fitton _et al_., _loc_. _cit_.) between volatile contents, moisture, ash and grindability Indices. Recently the author (Casshyap, 1960) carried out a preliminary study of grindability tests on the Karo seam on similar lines as followed by Ghosal _et al_. (_loc_. _cit_.).

Two machines are available for determining grindability of coal: (a) a Hardgrove machine which is a miniature ring-ball type pulverizer and (b) a ball-mill. The grindability tests are generally performed by the Hardgrove-machine Method (Grindability of coal by the Hardgrove Machine Method, A.S.T.M. Designation; 409-51, 1952, Pt. 5, p. 840).

The sample for the grindability test was prepared according to ASTM methods laid down in the tentative specification and that for the chemical analysis according to B.S. specification No. 1016 of 1942. Fifty grams of the closely-sized sample (passing through No. 14 B.S. test sieve and caught on No. 25 B.S. test sieve) were put in a Hardgrove machine and subjected to grinding at 60 revolutions with a standard loading of 64 lb. In order to assess the change in size, the ground product was then passed through a 200 mesh sieve. The Hardgrove grindability index of coal is expressed by the equation:

$$\text{Hardgrove Index} = 13 + 6.93\,W$$

where W is the weight of the ground sample which passes through a 200 mesh sieve.

The grindability tests were performed on 15 samples of the Karo seam. The 72 mesh fraction of each ground sample was subjected to proximate analysis in order to ascertain what relationship exists between its Hardgrove index and the chemical constituents.

The results of the grindability tests and proximate analyses are given in Table No. 12.

The coals of the Karo measures are medium volatile coals with low moisture and moderately high ash contents. Their HGI (Hardgrove Grindability Index) is found to vary from 60 to 78. The HGI for Kargali coals which are medium to high volatile has been reported by Ghosal _et al_. (_loc_. _cit_.) to vary from 48 to 68.

When the value of moisture content is plotted against the respective HGI, a direct relationship is seen to exist as shown in Fig. 15. For a change of moisture content from 0.2 to 0.8, the corresponding variation in the HGI is from 60 to 78. Fitton _et al_. (_loc_. _cit_., p. 58) have observed that for the values of moisture content upto 1 per cent,

TABLE NO. 12: GRINDABILITY INDEX AND PROXIMATE ANALYSES OF THE KARO MEASURE COALS.

S.No.	Sample No.	Proximate Analyses as calculated (per cent)				Dry basis (per cent)			d.a.f. (per cent)		Hardgrove Grindability Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon		
1.	Kc4	0.7	36.3	16.9	46.9	36.5	17.1	46.4	26.9	73.1	68	Dhori Colliery, Karo Plot No. C.
2.	Kc6	0.4	24.8	18.3	56.5	24.9	18.3	56.8	24.4	75.6	74	-do-
3.	KA2	0.3	20.9	18.4	60.4	21.0	18.4	60.6	23.0	76.7	76	Dhori Colliery, Karo Plot No. A.
4.	KA3	0.3	18.5	18.4	62.8	18.5	18.4	63.1	22.6	77.4	68	-do-
5.	KA5	0.3	18.6	18.0	63.1	18.6	18.0	63.4	22.1	77.9	78	-do-
6.	DKB2	0.4	14.8	19.8	67.0	14.8	19.9	75.3	23.4	76.6	75	Khas Dhori Colliery, Quarry No. 2.
7.	DKB5	0.3	14.3	21.4	64.0	14.3	21.5	64.2	25.1	74.9	68	-do-
8.	DKB7	0.3	22.7	17.9	57.1	22.8	17.9	57.3	23.3	76.7	70	-do-
9.	DKT1	0.3	22.9	22.5	54.3	23.0	22.6	54.4	29.3	70.7	66	Khas Dhori Colliery, Quarry No. 3.
10.	DKT2	0.7	22.4	21.0	55.9	22.5	21.1	56.4	27.2	72.8	64	-do-
11.	DKT5	0.3	20.1	22.9	56.7	20.1	23.0	56.9	28.8	71.2	69	-do-
12.	PKT2	0.8	28.7	22.7	47.8	28.9	22.8	48.3	32.1	67.9	60	Pichri Colliery,
13.	PKT5	0.7	19.5	20.3	59.5	19.6	20.4	60.0	25.4	74.6	70	-do-
14.	T2	0.3	14.3	24.8	60.6	14.3	24.9	60.8	29.0	71.0	66	Turio Colliery.
15.	T5	0.2	15.0	20.5	64.3	15.0	20.5	64.5	24.2	75.8	71	-do-

there is a wide variation in the values of grindability indices from 35 to 115.

The Hardgrove index is found to decrease with increase of volatiles (d.a.f.) as shown in Fig. 16. Ghosal et al. (1958) are of the opinion that high volatile coals having volatile matter (d.m.f.) between 35 to 50 per cent are difficult to grind, whereas coals which have medium and low volatile content (volatile matter between 20 to 30 per cent) are easy to grind.

As a result of these observations it is possible to say that the coals of the Karo measures are generally of medium rank and can be easily subjected to pulverization. The pulverized coal can be used in the manufacture of soft coke and also the pulverized fuel firing.

THE COAL SEAMS OF THE MAKOLI AREA

It has been mentioned in Chapter II that the coal seams of the Makoli area probably belong to the third subdivision of the Barakars (see p. 24). Ten representative samples of coal from these seams were analysed and the results are shown in Table No. 13.

The moisture varies from 0.2 to 0.3 per cent, ash from 10.4 to 29.2 per cent and volatiles from 2.17 to 26.0 per cent (d.a.f.). The nature of coke buttons and their caking and swelling index indicate that

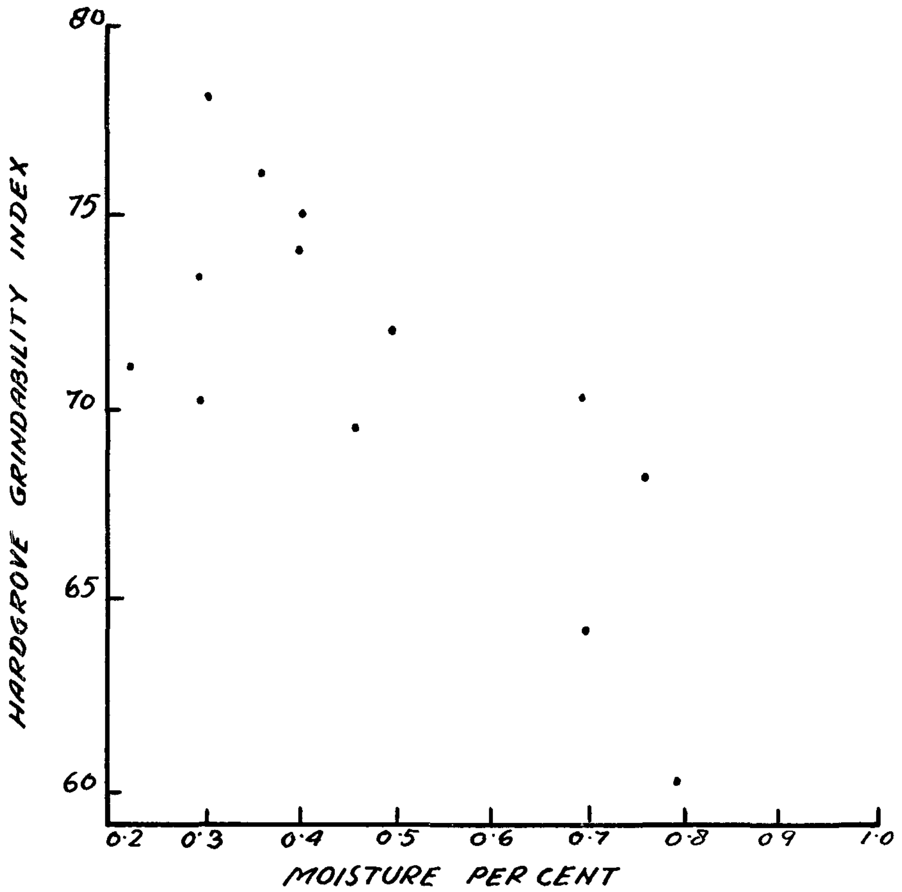

FIG. 15. MOISTURE & HGI RELATIONSHIP IN KARO Ms. COALS.

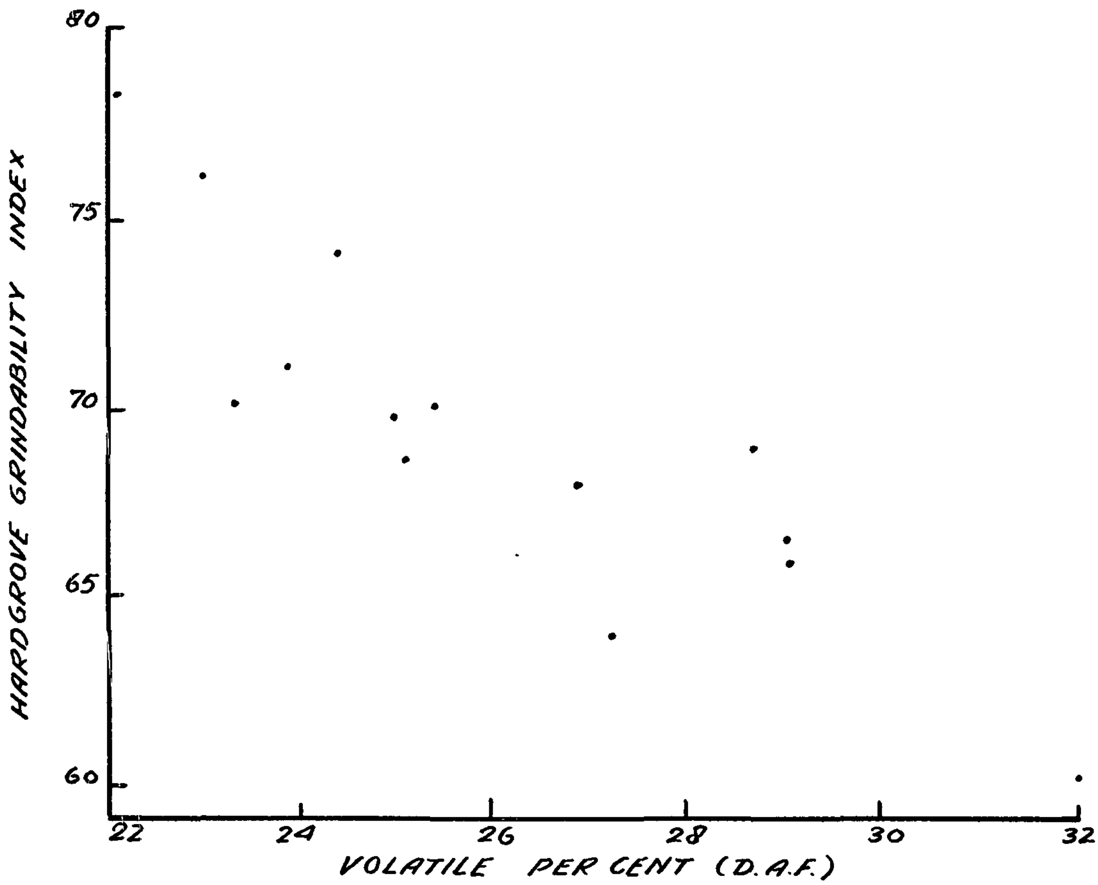

FIG. 16. VOLATILE & HGI RELATIONSHIP IN KARO Ms. COALS.

the coals are weakly to fairly coking. The calorific value as determined for one sample is 15,091 B.th.u./lb (d.a.f.). The Hardgrove Grindability index determined for five samples varies from 67 to 73 so that the coals can be easily pulverized and used in the manufacture of soft coke for domestic purposes.

THE 12-FOOT AND THE JARANGDIH SEAMS

The author has not come across any published work regarding the chemical nature of the coals of these two seams. Four samples from each of the seams were analysed and their results appear in Table No. 14.

In the 12-foot seam moisture varies from 0.2 to 0.6 per cent, ash from 27.7 to 33.1 per cent and volatiles from 31.4 to 37.6 per cent (d.a.f.). In the four samples analysed the coke buttons are fairly swollen (Cf) to firmly agglomerating (Af). The caking index for two specimens is 18 and their Swelling No. is 3 and 4½. The calorific value for one specimen is 14,819 B.th.u./lb (d.a.f.).

In the coals of the Jarangdih seam, moisture varies from 0.6 to 0.7 per cent, ash from 19.8 to 27.7 per cent and volatiles from 34.0 to 38.5 per cent (d.a.f.). The coke buttons are of fairly swollen (Cf) and firmly agglomerating (Af) types. The caking index for one specimen is 18 and Swelling No. for two specimens is 4 and 5. The calorific value is 14,746 B.th.u./lb (d.a.f.).

TABLE NO. 13: RESULTS OF THE PROXIMATE ANALYSES AND GRINDABILITY INDEX OF COALS FROM THE MAKOLI AREA.

S.No.	Sample No.	Seam	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Colour of Ash	Hardgrove Grindability Index	Locality	Horizon
			Moist.	Ash	Vola-tile	Fixed Carbon	Vola-tile	Fixed Carbon								
1.	NSD/1	12 ft. thick	0.3	13.4	19.4	66.9	22.4	77.7	Af	Fairly aggl., non-fiss.	-	-	Pinkish	73	New Selected Dhori Coll., Quarry No.2	Top
2.	NSD/2	12 ft. thick	0.2	16.3	21.7	61.8	26.0	74.0	Gp	Poorly swoll., strong.	-	-	Greyish white	71	-do-	5 ft. from Top.
3.	NSD/3	11 ft. thick	0.5	33.3	15.7	50.5	23.6	76.4	Af	Fairly aggl., non-fiss.	16	-	Creamish	70	New Selected Dhori Coll., Quarry No.1	Top
4.	NSD/4	11 ft. thick	0.3	14.4	19.1	66.2	22.3	77.7	Af	-do-	-	-	White	72	-do-	8 ft. from Top.
5.	NSD/5	9 ft. thick	0.3	17.2	19.8	62.7	23.9	76.1	Gp	Poorly swoll., strong.	-	-	Greyish	67	New Selected Dhori Coll., Incline No.3	Top
6.	NSD/6	9 ft. thick	0.2	17.4	20.1	62.3	24.4	75.6	Af	Fairly aggl., non-fiss.	-	-	Creamish	-	-do-	Bottom
7.	NSD/7	13 ft. thick	0.3	16.6	19.7	63.4	23.7	76.3	Af	Non-swoll., strong.	16	2½	Greyish	-	New Selected Dhori Coll., Quarry No.4	Top
8.	NSD/8	13 ft. thick	0.3	15.0	19.4	64.8	23.0	77.0	Gp	Greyish, slightly swoll., porous.	-	-	Pinkish	-	-do-	Middle
9.	NSD/9	13 ft. thick	0.4	18.1	20.2	61.3	24.7	75.3	Af	Non-swoll., fairly strong.	-	-	White with chocolate tinge.	-	-do-	Bottom
10.	NSD/10	12 ft. thick	0.3	14.8	20.6	64.3	24.2	75.8	Gp	Fairly swoll., non-fiss.	17	3½	Greyish with whitish tinge.	-	New Selected Dhori Coll., Quarry No.2	Middle

TABLE NO. 14: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE 12-FOOT, JARANGDIH AND BERMO SEAMS.

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B.Th.U./lb.		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality	Hos.
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis							
1.	KT/W/1	0.5	27.6	22.9	49.0	31.8	68.2	10,702	14,819	Creamish	Cf	Fairly swoll., lustr., metall.	18	4½	12-ft. seam Incl., Western Gallery.	Top 1 ft
2.	KT/W/3	0.6	32.9	24.0	42.0	37.6	62.4	-	-	-do-	Cf	Fairly strong and swoll., steel grey.	-	-	-do-	Top-6 ft.
3.	KT/E/2	0.2	26.8	24.7	48.3	33.8	66.2	-	-	Greyish white	Af	Firmly aggl., black.	-	3	12-ft. seam Incl., Eastern Gallery.	Top
4.	KT/E/3	0.3	28.2	22.5	49.0	31.4	68.6	-	-	White	Cf	Fairly swoll., with good cell structure.	18	-	-do-	Middl
5.	J1	0.6	24.7	28.8	46.9	38.5	61.5	11,089	14,746	Pinkish	Cf	Fairly swoll., and strong.	-	5	Jarangdih seam Incl., No. 3.	Top
6.	J5	0.7	19.6	27.1	52.6	34.0	66.0	-	-	Grey	Af	Fairly aggl., steel grey, non-swoll.	-	-	-do-	10 ft
7.	J7	0.6	27.5	26.6	45.3	37.0	63.0	-	-	Creamish	Cf	Fairly swoll. and strong.	18	4	-do-	15 ft
8.	J9	0.6	22.5	27.1	49.8	35.2	64.8	-	-	-do-	Af	Firmly aggl. and black.	-	-	-do-	18 ft
9.	B/3	0.2	18.8	21.9	59.1	27.1	72.9	-	-	Pinkish	Cf	Fairly strong and swoll.	-	-	Bermo seam quarry, Dhori Coll.	Top-5 ft.
10.	B/4	0.5	24.7	27.3	47.5	36.5	63.5	-	-	Light chocolate	Cf	-do-	-	-	-do-	8 ft.
11.	B/6	0.4	17.5	27.4	54.7	33.3	66.7	-	-	Pink	Af	Strongly aggl., black.	-	3	-do-	16 ft.
12.	B/8	0.3	22.6	20.1	57.0	26.1	73.9	11,175	14,457	Whitish	Af	Fairly strong and steel grey.	-	2½	-do-	22 ft.
13.	B/11	0.3	15.7	25.0	59.0	29.8	70.2	-	-	White	Cf	Fairly swoll. with good cell structure.	-	-	-do-	33 ft.

THE BERMO SEAM

A systematic study of the Bermo seam in the Kargali and Dhori areas was undertaken by the Fuel Research Institute in collaboration with the Damodar Valley Corporation (Fuel Res. Inst. & Damodar Valley Corp., Joint Publication, 1952) to investigate the possibilities of its beneficiation. At Kargali, the Bermo seam was studied in two equal sections, "Tops" and "Bottoms".

Five samples of the Bermo seam from the Bermo Seam Quarry of the Dhori colliery, were analysed. The results of analysis are given in Table No. 14.

The moisture varies from 0.2 to 0.5 per cent, ash from 15.7 to 24.8 per cent and volatiles from 26.1 to 36.5 per cent (d.a.f.). The calorific value for one specimen is 14,457 B.th.u./lb (d.a.f.). The buttons are fairly swollen to agglomerated (Cf to Af).

The Bermo seam of the Dhori area appears more mature as compared to that at Kargali (F.R.I. & D.V.C., Joint Publication, loc. cit., p. 25). The Bottoms are more amenable to washing than the Tops.

WEST BOKARO COALFIELD

THE KUJU SEAM

Chemical Analysis

The Kuju seam is the only important seam of the West Bokaro coalfield. It is being worked at several places but nowhere is the working well organized. Very little information is available regarding the chemical properties of this seam (Fox, 1934, p. 133).

Coal samples were collected from the collieries of Morpa, Kuju and the Haisaghara. The location of these collieries is shown in the map reproduced in Fig. 3. A section of the seam from the Kuju, Morpa and Haisaghara collieries is shown in Fig. 17 which also shows the position of 13 samples analysed. The results of the analysis are given in Table No. 15.

Moisture

The average moisture content is 1.4 per cent which is the highest recorded in the coal seams of the Bokaro coalfield in the present study.

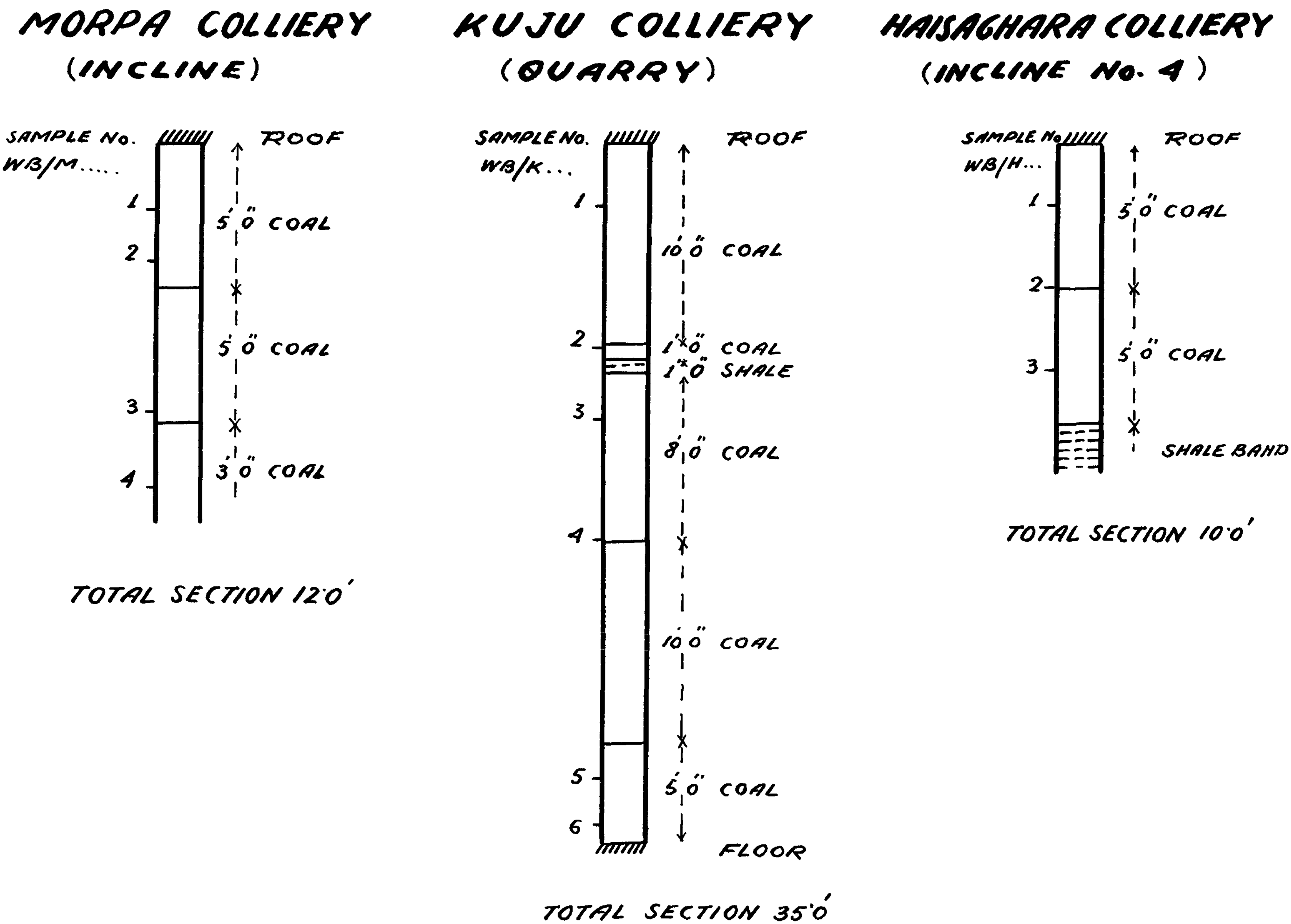

FIG. 17. SECTION OF THE KUJU SEAM.

TABLE NO. 15: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KUJU, NO. X AND NO. XI SEAMS OF THE WEST BOKARO COALFIELD.

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific Value B.Th.U/lb.		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
1.	WB/M1	1.3	17.0	26.7	55.0	32.8	67.2	-	-	Chocolate	Aw	Black, non-swoll., weak.	-	-	Horpa Coll., Kuju seam.
2.	WB/M2	1.4	11.8	31.1	55.7	35.8	64.2	-	-	Pinkish	Af	Grey, non-swoll., strong.	-	2½	-do-
3.	WB/M3	1.3	8.7	34.3	55.7	38.1	61.9	13,318	14,798	Pink	Cg	Grey, Mod. swoll.	17	3½	-do-
4.	WB/M4	1.2	10.9	33.5	54.4	38.1	61.9	-	-	Creamish	Cg	Slightly swoll., porous, silver white.	18	-	-do-
5.	WB/K1	1.2	15.2	32.1	51.5	38.4	61.6	-	-	Creamish	Aw	Non-swoll., fiss.	-	2	Kuju Coll., Kuju seam.
6.	WB/K2	1.1	17.0	31.6	50.0	38.6	61.4	11,412	13,128	Creamish white	Af	Non-swoll., fairly strong, slightly fiss., dull grey.	17	-	-do-
7.	WB/K3	1.5	9.9	31.4	57.2	35.4	64.6	-	-	Dirty white	Cf	Slightly swoll., slightly porous.	-	-	-do-
8.	WB/K4	1.5	7.1	34.7	56.7	37.9	62.1	-	-	White	Cg	Slightly swoll., lustr. metall.	18	-	-do-
9.	WB/K5	1.5	8.0	32.1	58.3	35.5	64.5	13,163	14,561	White	Aw	Blackish, fiss., breaking easily, strong.	16	2	-do-

TABLE NO. 15: RESULTS OF THE PROXIMATE ANALYSES AND COKING CHARACTERS OF THE KUJU, NO. X AND NO. XI SEAMS OF THE WEST BOKARO COALFIELD (CONTINUED).

S.No.	Sample No.	Proximate analyses (per cent)				Calculated on dry, ash-free basis (per cent)		Calorific value B.Th.U/lb.		Colour of Ash	Classified coke button	Volatile coke button	Caking Index	B.S. Swelling Index	Locality
		Moist.	Ash	Volatile	Fixed Carbon	Volatile	Fixed Carbon	As determined	On d.a.f. basis						
10.	WB/K6	1.5	11.4	29.8	57.3	34.3	65.7	-	-	Creamish	Af	Aggl., hard.	-	2½	Kuju Coll., Kuju seam.
11.	WB/H1	1.4	24.1	28.3	46.2	38.0	62.0	10,187	13,674	Grey	NAb	Non-aggl., powdery, black.	Non-caking.	-	Haisaghara Coll. Kuju seam.
12.	WB/H2	1.6	27.7	26.4	44.3	37.3	62.7	-	-	Dirty white	NAb	-do-	-do-	-	-do-
13.	WB/H3	2.2	29.9	26.0	41.9	37.8	62.2	9,115	13,116	Creamish	NAb	Crumbles to powder with slight pressure.	-do-	-	-do-
14.	WB/A3	0.3	21.6	23.7	54.4	30.3	69.7	11,859	15,859	Brownish	Cf	Mod. swoll., lustr. metall.	19	5	Arrah Coll., No. X seam.
15.	WB/A4	0.3	23.2	22.1	54.4	29.6	70.4	-	-	Light brown	Af	Non-swoll., strong.	-	-	-do-
16.	WB/S1	0.3	23.6	17.8	58.3	23.3	76.7	-	-	Greyish white	Aw	Non-swoll., fiss., black.	-	-	Sarubera Coll., No. XI seam.
17.	WB/S4	0.4	16.0	20.3	63.3	24.3	75.7	12,906	15,365	Creamish	Cg	Black, slightly swoll., porous.	-	-	-do-
18.	WB/S5	0.3	19.2	18.8	61.7	23.2	76.8	-	-	Whitish	Af	Non-swoll., aggl.	-	-	-do-

Ash

The ash percentage of coals from the collieries of Morpa and Kuju is considerably lower (7.2 to 17.2 per cent) as compared to that in the Haisaghara colliery (24.4 to 30.5 per cent). The average ash percentage in the three collieries is as follows:-

Colliery		Ash per cent (dry basis)
Morpa	...	10.7
Kuju	...	11.4
Haisaghara	...	23.0

Volatile

The volatile matter on dry-ash-free basis ranges from 32.8 to 38.6 per cent and is the highest recorded in the Bokaro coalfield in the present study.

Carbon, Hydrogen and Sulphur

Carbon and hydrogen have been determined in two and sulphur in five specimens.

The percentage of carbon is 82.46 and 83.17 (d.a.f.) and that of hydrogen is 5.26 and 5.24 (d.a.f.). These coals are slightly lower in rank as compared to those of the Kargali and Karo seams. The total sulphur varies from 0.75 to 1.05 per cent (d.a.f.).

Calorific Value

Calorific value determined in five samples varies from 13,116 to 14,798 B.th.u./lb (d.a.f.). The high volatile and ash contents account for the low calorific value.

Coking Characters

Coke Button

The coke buttons are generally non-swollen, being weakly to fairly agglomerating (Aw to Af). Poorly to fairly swollen coke buttons (Cp to Cf) are also present. Some coals from the Haisaghara colliery are non-swollen and non-agglomerating and yield a pulverulent residue which is indicative of non-coking character.

Caking and Swelling Index

The caking index is generally between 16 and 18. The three specimens from the Haisaghara colliery did not form a coke button. The Swelling No. varies from 2 to 3½.

The presence of comparatively higher moisture and volatile contents and lower calorific value in coals of the Kuju seam indicates that these coals are less mature. Although there are some horizons of good to fairly coking coals in this seam, the coals are generally non to poorly coking. Fox (1934, p. 132) quoted analyses of the Kuju seam and suggested that normally the coals should not be of caking quality. These coals may, therefore, be placed between the B4 and B5 Groups — high volatile (semi-caking) and high volatile (non-caking) — of the bituminous coals (General Classification of Indian Coals, ISI, loc. cit.) and the coals may be used in gasification, steam raising and long flame heating.

THE NO. X AND NO. XI SEAMS

Two samples of coal from seam No. X and three from No. XI were analysed and their results are included in Table No. 15. In the specimens of No. X seam moisture is 0.3 per cent, ash varies from 21.7 to 23.3 per cent and volatiles from 29.6 to 30.3 per cent (d.a.f.). The calorific value for one specimen is 15,859 B.th.u./lb (d.a.f.). The coke button is fairly agglomerating (Af) to good swollen (Cg).

In seam No. XI moisture varies from 0.3 to 0.4 per cent, ash from 16.0 to 23.7 per cent and volatiles from 23.2 to 29.6 per cent (d.a.f.). The calorific value for one specimen is 15,365 B.th.u./lb (d.a.f.). The coke button is weakly agglomerating (Aw) to good swollen (Cg).

CHAPTER V

MICROSCOPIC STUDY OF COAL

An examination of the physical and chemical properties of the coal constituents and their petrological studies are important for efficient utilization of coal resources. A detailed study of the micro-constituents is essential in determining the nature, origin and composition of the coal ingredients.

Although the vegetal origin of coal was established towards the end of 18th century (see Stopes and Wheeler, 1924, p. 4), it was in 1833 and 1834 that Witham and Hutton applied for the first time the use of microscope to the investigation of coal (see Stopes and Wheeler, loc. cit., p. 179). This was the beginning of a new chapter in coal science and an extensive list of publications mainly from workers in England and Germany accumulated by the end of the 19th century. Among the many workers who contributed to this subject, mention may be made of Petzholt (see Hickling, 1917, p. 3); Daubree (see Moore, 1947, p. 174); Schultze, Dawson, Reinsch, Zeiller, Renault and Bertrand (see Stopes and Wheeler, 1924, p. 180-188).

In the first quarter of the twentieth century comprehensive studies were undertaken simultaneously in England, Germany and America and important contributions were made towards improving the technique of section making and of deciphering the nature and structure of vegetal constituents composing coal (Lomax, 1911; Winter, 1913; White and Thiessen, 1913; Jefførey, 1914, 1915; Hickling, 1916, 1917). By this time though about a century had passed since investigation on coal first commenced, there was no general agreement regarding the nomenclature of coal for hand specimen and thin-section study. The terms "bright" and "dull" coal, "cannel coal", "humic coal" and "sapropelic coal" were being used loosely for many years in England and Europe to distinguish between the various types of coal. The Germans had used the terms "Glanzkohle", "Mattkohle" and "Faserkohle", for bright coal, dull coal and mineral charcoal respectively, while the French had used the terms "Lames claires", "Houille folaire", "Houille greme" and "Fusain" for bright coal, striated bright coal, dull coal and fusain, respectively (see Francis, 1954, p. 273).

Stopes (1919) presented for the first time a macroscopic classification of coal by recognizing four distinct bands in the British Palaeozoic bituminous coals. She named these macroscopic units as vitrain, clarain, durain and fusain. Definite narrow bands of black colour having glossy lustre and a conchoidal fracture were identified by Stopes as vitrain. Clarain was considered a composite mass of closely spaced streaks of vitrain exhibiting silky lustre. Dull hard bands showing an irregular fracture were termed durain. These often contain streaks or flecks of vitrain. Fusain occurs in flat discontinuous eye-shaped patches or lenticles generally parallel to the bedding plane. It crumbles easily to fine powder and blackens the fingers.

In America a different terminology proposed by Thiessen (1920) was adopted. Thiessen used the term 'anthraxylon' (wood) for bright components of coal and for the dull components consisting of an assortment of miscellaneous debris, he proposed the term "attritus". The Germans called the four ingredients as vitrit, fusit, clarit and durit.

Stopes was of the opinion that under the microscope vitrain is homogeneous and translucent and is devoid of any structure, resembling a hardened jelly. Lomax (1911, 1914), however, demonstrated well preserved plant tissues which he described as "Jetonized wood". Some well preserved structures apparently those of Myeloxylon bark were reported by Hickling (1917).

Winter (1913) also considered vitrain to be structureless, while Potonie (1926) recognized three types of bright components, "eu-vitrit" for structureless variety, "lignitoid vitrit" for vitrain derived from wood and "suberitoid vitrit" for vitrain derived from cork. Duparque (1926) similarly recognized all gradations of vitrain, from the structureless to completely structured varieties and proposed the terms "xylain" for the structured and "xylo-vitrain" for the structureless varieties. In America, Jeffrey (<u>loc</u>. <u>cit</u>.) proposed the term "lignitoid" for vitrain bands composed of wood. The terms used by Thiessen (<u>loc</u>. <u>cit</u>.) applied both for hand specimen and thin-section study.

In order to avoid the increasing confusion which arose from these different attempts at defining coal types, a number of leading coal petrographers met in 1932 to harmonise the nomenclature of various coal types taking into consideration the progress achieved since 1919 (see Seyler, 1943). Stopes (1935) came forward with an amended system of nomenclature and proposed that the earlier known macroscopic units i.e., vitrain, fusain, clarain and durain should be restricted to the 'rock types' as seen in the hand specimen. She suggested a new term "maceral" for the petrological units of coal seen under microscope in thin section or polished surfaces. Each maceral is to end in the termination — inite e.g. the maceral for vitrain is 'vitrinite', for fusain, 'fusinite' for spore exine, 'exinite' for cuticle, 'cutinite' and so on. The transition stages between vitrinite and fusinite were termed 'vitro-fusinite' or 'fuso-vitrinite'.

This simplified form of Stope's nomenclature was proposed by Seyler and accepted at the Second International Stratigraphical Conference held at Heerlen in 1935 (Jongmans, Koopmans and Roos, 1936).

Marshall (1955) and Ganju (1955) have cast doubts on the correctness of Stopes definition of 'macerals'. The macerals have been regarded by Stopes as 'complex of biological units' or 'macerated fragments of vegetation' of which the coal types are composed. The identification of macerals is based mainly on the form and nature of organic entity recognizable under the microscope. Stopes does not stress the importance of their composition i.e. the actual substance of which the coal types are now composed (Marshall, loc. cit., p. 762). Cady (1942) in attempting to resolve this ambiguity proposed the term "phyteral" to designate vegetal fragments or "fossils" in coal as distinguished from the actual substance of which the fragments or "fossils" may be composed. Marshall (*loc. cit.*) agrees with this view. Except for these minor points of objection, it is perhaps true to say that Stope's (1935) amended classification has assisted greatly in the description of coal ingredients.

In the Heerlen conference of 1951, Stope's system of nomenclature was slightly modified in the light of some new observations made by reflected light technique (see Krevelen and Schuyer, 1957). The maceral vitrinite was subdivided according to whether it is structured — 'tellinite' or structureless — 'collinite'. A new maceral 'sclerotinite', was adopted for describing the fungal matter in coal. At the instance of German coal petrographers, two forms of micrinite, the 'granular' and 'massive', were adopted.

Thiessen on the basis of thin-section study observed as early as 1913 that woody tissues of plants had mostly contributed to formation of coal (Thiessen, 1913). Hickling (1917), however, arrived at the conclusion that in the Palaeozoic British coals, the cortical and not woody tissues were important as source material. Subsequent studies on British coals by Seyler (1925), Evans, Slater and Wheeler (1929), Hickling and Marshall (1932), Boddy (1934), Raistrick and Marshall (1939) and Marshall (1943) showed that both wood and bark have entered into the formation of vitrain in the British coals. Thiessen (1929) and Thiessen and Sprunk (1931, 1935) revised their earlier views and concluded that bark also constituted the anthraxylon of American coals, though the proportion of wood always exceeded the bark. Marshall (1941), however, observed that like the British coals a greater part of the American anthraxylon was made up of cortex.

Our present knowledge of vitrain shows that it is generally formed of wood and bark tissues. The cell cavities may be filled with original resinous material or with that absorbed from peat. In some cases the cell contents are formed of the disintigration product of the cell walls (Hickling and Marshall, 1933). The latter process was considered by Thiessen and Sprunk (1936) as important in the production of granular opaque matter. Dr. Ganju holds similar views regarding the formation of granular material in Indian coals (Ganju, 1955).

Widely divergent views have been expressed regarding the origin of fusain. Daubree (see Moore, 1947), White and Thiessen (1913), and Jefførey (1915, 1925) believed forest fires to be the chief cause of the formation of fusain. White (1925) later amended his views and explained that fusain had originated from dried wood which was covered and protected by a film of ulmins. Stach (1926) agrees in principle with White's contention. Taylor (1926, 1927, 1928) proposed the 'Base Exchange' theory for the formation of fusain and for rank variation in coals. Lange (1928) observed that not only wood but other parts of the plant could provide material for the formation of fusain. In a recent paper Marshall (1954) is of the opinion that there are two varieties of fusain (fusinite). The first variety is formed of well preserved long fibres of fusinite which has originated in situ as a result of local biological and chemical action during the early stage of seam history. The lustúreless fusinite constitutes the second variety which could be formed through the agency of fire.

Opaque or semi-opaque constituents which often form important ingredients of durain have been identified by Thiessen and Sprunk (1935) as "cell-wall degradation matter". Hacquebard (1952) made a comprehensive study of the opaque matter in coals of bituminous and anthracitic rank and recognized two kinds of opaque matter, the primary opaque matter formed or incorporated in the peat stage in an opaque condition and secondary opaque matter formed as a result of metamorphism.

Spores, cuticles and resins occur in varying proportion in the Palaeozoic coals. Extensive studies have been made of these plant constituents and their possible use in the correlation of coal seams (Slater, Evans and Eddy, 1930; Raistrick and Simpson, 1933; Raistrick and Marshall, 1939; Sahni, 1941; Sen, 1944; Virkki, 1945; Dulhunty, 1947; Knox, 1948; Ghosh and Sen, 1948; Dijkstra, 1951; Stach, 1954; Hacquebard, 1955; Ganju, 1955, 1956, 1960). Similarly algal bodies which form an important constituent of certain coals have been studied in detail by Temperley (1936), Blackburn and Temperley (1936) and Kosanke (1950).

The study of polished sections of coal has opened new fields of research in coal petrography. About 1913, Winter in Germany developed the method of microscopic examination of polished surfaces of coal in reflected light by using dry objectives and etching the coal in Schulze's solution. In 1930 Stach, Hoffman and Kuhlwein (see Seyler and Edwards, 1949) improved the technique considerably by using oil immersion objectives. The technique is now so perfect that practically all the constituents can be examined in polished surfaces (Stach, 1928, 1934, 1937, 1949). Valuable contributions in this line have been made by Abramski, Mackowski, Mantel and Stach (1951), Teichmüller (1940, 1950, 1952), Stach (1954, 1955), Teichmüller and Thomson (1958).

The merits and demerits of the above technique have been discussed recently by Marshall (1955), Ganju (1955) and Hacquebard (1955). These workers hold the view that examination of coal by reflected light is advantageous for all ranks of coal as compared to the thin-section study which is more useful in the investigation of translucent components. Dr. M. Teichmuller introduced a new technique of studying the polished thin sections of coal (Teichmuller, 1952).

In the earlier studies attention was paid merely to the qualitative aspects of coal components. It was only after the development of micro-photometer by Berek in 1930 that attention was paid to the optical properties of coal. Though Hoffman and Jenker (1933) were probably the first to measure the reflectance of vitrinite of different rank, a real impetus to this subject was given by Seyler (1943). He measured the reflectance of a large number of samples and concluded that coal formed from lignified plant tissues is composed of a number of "optical components", from 0 to 9, the reflectance increasing discontinuously with rank.

Since the appearance of Seyler's theory many workers have made further contributions on the reflectance of coal. Some of them have accepted with minor modifications the theory as stated originally (Sherlock, 1951; Mukherjee, 1952; Huntjens and Krevelen, 1954); others have rejected it altogether (Dahme and Mackowski, 1950; McCartney, 1952;

Broadbent and Shaw, 1955; Siever, 1957). The author's observations which agree with Seyler's views on this subject are recorded in a separate chapter.

The X-ray studies of coal have also yielded valuable information regarding its structure. In India Prof. Mahadevan initiated the technique in 1929 and applied the X-ray diffraction method for determining the constitution of coals. His studies in the first instance were confined to vitrains and durains (Mahadevan, 1929, 1930) but were extended later to the resins of various kinds (1931). In the recent years valuable contributions have been made on this subject by various workers (Siever, 1952; Dryden 1953; Mitra, 1954; Dorman <u>et al</u>., 1957; Ergun and Wender, 1958).

Studies in coal petrology have been initiated in India only recently by Prof. P.N. Ganju, who has made valuable contributions on the microstructure of Indian coals (Ganju 1955, 1955a, 1955b, 1956, 1958, 1960).

The only known important reference on the microstructure of Bokaro coals is by Dr. Ganju (1955). Microscopic characters of some coals of the Bermo seam have been described by the Fuel Research Institute (Damodar Valley Corporation & Fuel Research Institute, Joint Publication 1952, p. 3).

The present study is based on the examination of 300 thin and 25 polished sections of coal. The distribution of the specimens collected from the productive coal seams of the Bokaro coalfield is as follows:-

Coalfield		Thickness in feet	No. of collected specimens	No. of thin sections prepared	No. of polished sections prepared
East Bokaro					
12-foot A	seam	12	9	9	
Jarangdih	seam	20	12	11	
Kargali	seam	100	194	188	13
Bermo	seam	45	13	11	
Karo	seam	80-100	62	59	7
West Bokaro					
Kuju	seam	40	15	13	5
No. XI	seam	30	5	5	
No. X	seam	20	4	4	

The technique used in the preparation of thin and polished sections of coal is more or less the same as adopted by Dr. Ganju (Ganju, 1955; p. 52-56).

PETROGRAPHY

A typical block of coal from the Kargali seam shown in Plate 5, Fig. 1 is composed of closely spaced vitrain bands which are upto 6 mm. in width and show often a silky lustre. Durain is grey, dull and hard and encloses shreds of vitrain. Fusain is less conspicuous and occurs in small irregular patches.

Coals of the Bermo, 12-foot and Jarangdih seams are similar to those of the Kargali seam. A representative block of coal from the Karo seam which appears in Plate 5, Fig. 2 shows that durain is a dominant constituent of these coals, while vitrain is present as a subordinate constituent.

A typical specimen of the Kuju seam, the only important seam of the West Bokaro coalfield, resembles that of the Kargali seam. Vitrain occurs in distinct bands and forms an important constituent of these coals, while fusain is less conspicuous. Coals of the No. X and No. XI seams are generally dull in appearance.

VITRINITE

A. Woody Tissue (mainly gymnospermous) preserved as Vitrinite

Woody tissues form a dominant constituent of the Bokaro coals. An important feature is that the cells are generally distorted. The tissue in Plate 6, Fig. 1 is characterized by closely spaced tracheids, showing distinct walls. Pale coloured oval resins occur abundantly. Medullary ray cells and chains of bordered pits are also noticed in the tissue. The pale resinous substance filling the ray cells frequently encloses gas bubbles and an opaque matter, as seen in the middle right-hand part of the figure. Another well preserved woody tissue cut longitudinally is illustrated in Plate 6, Fig. 2. In the right-hand side, the fibre walls show rows of pits.

Other woody tissues are considerably compressed and do not show any structural details. Plate 6, Fig. 3 illustrates what is probably a longitudinal section of a woody tissue with pale coloured, compressed and contorted cells with the lumens filled with an opaque matter. Marshall (1941) observed a similar structure in the Carboniferous coals of America and interpreted the pale golden strips as the "inner linings" of cell walls. They are contorted, inrolled and often forked and swollen at the ends. In those cells which are not much compressed, the lumens are seen to enclose an opaque granular material, a feature shown in the lower left-hand side of the figure.

A conspicuous feature of the woody tissue is the presence of resin-filled medullary ray cells in fair abundance. These have been observed both in the longitudinal and transverse sections as illustrated in Plate 6, Figs. 4 and 5 and Plate 7, Figs. 1 and 2. Plate 6, Fig. 4 shows oval medullary ray cells filled with a pale resinous substance often enclosing gas bubbles. It is interesting to observe that these cells are usually constricted in the central part and bulged out at one or both ends. Dr. Ganju (1955) has described similar tissues in the Karanpura coals. Plate 7, Fig. 2 shows rows of compressed and twisted medullary ray cells occurring in a thin-walled tissue.

Large cylindrical thin-walled cells in a woody tissue appear in Plate 7, Fig. 3. The cells seem to be attached at the ends by a ball and socket joint as seen near the top right-hand side. In some cases the adjoining ends are connected by tube-like projections, a feature seen in the middle left-hand side of the figure. In other cases the cells are considerably squeezed at one or both the ends.

Woody tissues filled with opaque granular & brown fragmental matter

A characteristic feature of certain coals, especially those of the Kargali seam, is the presence of finely granular and coarse fragmental matter in the cells of woody tissues constituting the vitrinite bands. This material is generally seen filling the lumens of cells, but sometimes it may constitute the main component of the decomposed tissue in durain. The nature and origin of this material is discussed below.

Granular matter

A transverse section of a woody tissue showing opaque granular matter is illustrated in Plate 7, Fig. 4. The bordered pits are fairly abundant producing X-shaped chains in the cell wall. It is noticed that the dark granular material appears translucent where the section tends to be thinner as in the upper centre of the figure and opaque where the section is thicker.

Tracheids filled with opaque granular matter are shown in longitudinal section in Plate 7, Fig. 5. Pale coloured resin-filled medullary ray cells, often compressed at the ends, are also conspicuous. The tissue shown in Plate 8, Fig. 1 is compressed and the swollen medullary ray cells show irregular shapes. The dark areas represent the lumens filled with opaque granular matter. Plate 8, Figs. 2 to 4 show more or less the same type of structure. A noteworthy feature in Plate 8, Fig. 2 is that the cell walls are invariably thickened at the corners. Plate 8, Fig. 3 shows alternate bands of thick-and thin-walled cells, while Plate 8, Fig. 4 illustrates a thin-walled tissue with compressed cells. The lumens in each case are filled with fine opaque granular matter which appears homogeneous. Pale coloured resin-filled medullary ray cells occur in parallel rows in both the tissues.

<u>Coarse fragmental matter</u>

The coarse fragmental matter filling the cells of the woody tissues is heterogeneous and comprises of angular bits of decomposed cell wall in varying degree of translucency. This material is also found to occur as a heterogeneous mass in the durains. A typical section is illustrated in Plate 8, Fig. 5 in which the cells of a woody tissue show distinct middle lamellae enclosing a mass of decomposed fragmental matter. Near the lower left-hand side the durain is largely comprised of this matter.

Plate 9, Fig. 1 illustrates a similar structure with the difference that finely granular material fills the lumens here. In the central part of this figure the cell walls are no longer preserved but the fine granular material forms a dense mass. Thiessen and Sprunk (1936) have observed a similar feature in which normal strands of anthraxylon were totally decomposed into an opaque mass enclosing remnants of broken cell walls. Plate 9, Fig. 2 shows a dense opaque mass of similar nature in a band of vitrinite.

The nature and origin of this material has been discussed by Hoffman and Stach (1931), Hickling and Marshall (1933), Thiessen and Sprunk (1935, 1936) and more recently by Ganju (1955). The generally accepted views regarding the mode of origin of these constituents are those by Thiessen and Sprunk. According to these authors biological decomposition of secondary walls of tracheids has resulted in the formation of the finely granular material (Thiessen and Sprunk, 1936) and decomposition of the primary walls and middle lamellae have produced the coarse translucent matter (Thiessen and Sprunk, 1935). Barghoorn and Scott (1958) have also discussed the problem of degradation of the plant cell walls and have arrived at similar conclusions.

Thus in coals of the Kargali and Kuju seams the decomposition of vegetal constituents by micro-organisms appears to have taken place in the early history of their formation. Plate 9, Fig. 3 shows an advanced stage in the process of degradation in vitrinite.

Bogen Structure

This structure is frequently met with in fusinite (White, 1925; Stach, 1926). Hickling and Marshall (1933) and Ganju (1955) have observed it in 'vitri-fusain', a transitional stage from vitrinite to fusinite. Plate 9, Fig. 4 shows a tissue with fractured cells producing a typical pattern of this type. The opaque mass in which the cell walls lie represent the lumens filled with fine granular material.

Microtectonics in woody tissue

In addition to the structures described above, the microscopic examination has brought to light some other interesting features which indicate that the coals have suffered compression by earth movements. Similar features have been observed by several workers in Germany amongst whom mention may be made of Sanders, Bode, Hohne, Duparque, Hoffman etc. (see Stach, 1949, p. 234). Sanders and his colleagues were probably the first to observe 'microtektoniks' in coal. Hohne was able to differentiate between microtectonics and macrotectonics. Recently M. Teichmüller and R. Teichmüller have discussed the microtectonic deformation of coal. These authors believe that micro-deformations of coal and bituminous shales represent typical examples of the large scale structures (M. Teichmüller and R. Teichmüller, 1954).

Plate 9, Fig. 5 and Plate 10, Figs 1 to 3 show some typical examples of microtectonics in woody tissue. Plate 9, Fig. 5 is a simpler case in which the tissue has been crumpled and rows of bordered pits are observed in the cell walls. A similar kind of structure is seen in Plate 10, Fig. 1 where woody fibres are much distorted in the central part. A resinous body lying in this region has not been compressed probably due to its hard nature. The intensely crumpled woody fibres in the upper middle portion of the figure recall an over-fold structure. In Fig. 2 the compressed tissue shows a folded structure which is fractured and slightly displaced at three or four places. The planes of fracture are sub-parallel and clearly observed in the arched tissue. Fig. 3 illustrates a different phenomenon which is not commonly observed in coal. The entire vitrinite band appears to have been mylonised producing sharply angular to sub-angular fragments of different size. The interspaces are filled with a finely divided matrix which has been derived from the vitrinite fragments.

As the vitrinite fragments are angular and poorly sorted and the matrix is produced from these fragments, there is little doubt that penecontemporaneous brecciation of the tissue at the site of deposition has taken place. The phenomenon may be compared to the formation of

Intraformational breccia which is defined by Pettijohn (1956, p. 276) as "the penecontemporaneous fragmentation and redeposition of the stratum". Regarding the conditions responsible for producing this type of fragmentation, Pettijohn states that "though fragmentation conceivably can be the result of several different processes, most commonly it appears to be caused by shoaling and temporary withdrawal of the waters followed by desiccation and mud cracking".

B. Bark tissue preserved as Vitrinite

Bark occurs less commonly but it exhibits well preserved structures. Plate 10, Figs. 4 and 5 and Plate 11, Fig. 1 illustrate some good examples of transversely cut bark tissue.

Plate 10, Fig. 4 shows vitrinite tissue exhibiting well preserved thick-walled polygonal cells of bark. The middle lamellae and triangular intercellular spaces filled with a golden yellow coal substance are conspicuous. The cell wall shows lamellar structure as a result of absorption of cell contents by the wall and its subsequent compression. The lumens are small and contain a dark brown substance.

The bark tissue sometimes shows alternate bands of thick- and thin-walled cells which are observed in Plate 10, Fig. 5 and Plate 11, Fig. 1. The thin-walled tissue is compressed and the individual cells are not clearly discernible; the thick-walled cells show small lumens filled with a dark material. The thick-walled cells in Fig. 1 show curved margins and pointed corners, a feature produced probably as a result of fracturing. The same type of structure appears in Plate 11, Fig. 2, where the tissue is broken into blocks of different size. The broken blocks probably formed a part of the vitrinite tissue lying near the lower margin of the figure. The bark tissue may be folded as in Plate 11, Fig. 3, where alternate rows of thick-and thin-walled cells are seen compressed and folded.

C. Secondary bark tissue preserved as vitrinite

The secondary bark has not contributed much to the formation of vitrinite in the Bokaro coals. A tissue exhibiting serially arranged rectangular thin-walled cells of secondary bark is shown in Plate 11, Fig. 4. The cells are filled with a pale or brownish fluid and do not show any other noticeable features. The dark coloured cell walls are conspicuous throughout the tissue.

Secondary bark (cork) sometimes alternates with bands of thick-walled cells as shown in Plate 11, Fig. 5. The secondary tissue is composed of thin-walled rectangular cells. The thick-walled cells are rhomb shaped exhibiting lamination, a feature noticed clearly in the lower right-hand side of the figure. The various zones are alternately brown and pale yellow and three or four such zones may be observed in cell. This tissue also includes stone cells showing 6 to 10 canals in the cell wall as seen in the lower right-hand side of the figure.

FUSINITE

Fusinite constitutes a minor ingredient of these coals and occurs in bands and lenticles. Typical examples of woody tissue preserved as fusinite are illustrated in Plate 12, Figs. 1 and 2. The tissues are cut transversely, with the thick-walled rectangular cells showing a characteristic serial pattern. Near the upper right-hand corner and along the lower margin in Fig. 1 the cells exhibit signs of crushing. The lumens are filled with a finely crystalline clay mineral which shows high birefringence. Both the tissues show characteristic scalariform thickenings.

DURAINS

Three types of durains have been observed in the various seams.

(a) Fibrous durain

This type has been observed to occur abundantly in the Kargali, Kuju and Bermo seams. The presence of well bedded vitrinite strips is a characteristic feature of this type which is illustrated in Plate 12, Fig. 3. Thin shreds of vitrinite form the dominant constituent and these are mixed up with micrinite, microspores and finely granular mineral matter composed of quartz, muscovite and kaolinite. An oval dark brown resin is conspicuous in the centre of the figure. A similar type of durain showing long fibres of vitrinite appears in Plate 12, Figs. 4 and 5 and Plate 13, Fig. 1. Finely granular mineral matter composed largely of quartz, is fairly abundant in Fig. 5 while dark brown resins are observed in Fig. 1. Megaspores are rare and a folded exine is seen near the lower edge in Fig. 1. Some durains of Kargali and Kuju seams include cuticles showing toothed and corrugated outlines as shown in Plate 13, Fig. 2.

(b) Durain produced as a result of degradation

This type of durain is prominent in certain sections of the Kargali and Kuju seams. The chief constituent is the woody degradation matter which is comprised of pale yellow or dark brown and opaque parts of decomposed cell walls. These two forms of degraded matter were described by Thiessen and Sprunk (1935) as 'Translucent humic matter' and 'Brown matter' respectively. A typical example of this class of durain is illustrated in Plate 13, Fig. 3. The original tissue present in the right-hand side of the figure shows signs of decomposition here and there.

The resins also form a part of this durain. Plate 13, Fig. 4 shows oval and rounded resin bodies with a pale narrow outer border and a brownish central zone which encloses gas bubbles and an opaque granular substance. Microspores and grains of quartz are fairly conspicuous amongst the finer ingredients.

A significant feature of this durain is that its constituents are similar to the brown fragmental matter observed in the lumens of the cells of woody tissue constituting vitrinite bands. As explained earlier micro-organisms are most probably responsible for the formation of this durain.

(c) <u>Durain with opaque attritus</u>

The third type of durain differs from the first two in that the opaque matter is its prominent component and vitrinite is scarce. These durains generally include a greater proportion of mineral matter. Plate 13, Fig. 5 represents a typical example of this type of durain. The opaque matter is composed of micrinite and fusinite and the mineral matter includes quartz and muscovite. An angular grain of quartz is observed in the lower left-hand corner, while a flake of muscovite showing well developed cleavage is conspicuous in the lower central part of the figure.

MINERAL MATTER

The mineral matter forms an essential component of coal and occurs disseminated in varied proportion in the durain, fusinite and vitrinite. The mineral matter in coal may be 'inherent' or extraneous. The 'inherent' matter includes the inorganic constituents present in the coal forming plants and forms an insignificant amount of the ash. The main part of the ash is constituted of extraneous matter and it is important to study the nature and origin of these minerals.

Mackowski has observed two types of inorganic mineral impurities in coal which may be introduced at different periods:

(1) Syngenitic mineral matter. This is introduced in the early stage of the formation of coal, that is during the biochemical change.

(2) Epigenitic mineral matter. This is incorporated during the maturing process after the completion of biochemical change.

The syngenitic group of minerals occur more frequently in coals and may include 'allogenic' and 'authigenic' types. The allogenic minerals are those which are derived from the pre-existing rocks and are transferred to the place of deposition. These include grains of quartz, mica, zircon etc. 'Authigenic' minerals, on the other hand, originate in the place of deposition and include kaolinite, siderite, calcite, pyrite, etc.

The epigenitic minerals are formed by solutions like iron sulphides or carbonates. Such minerals occur as components of fusinite or as films in shrinkage cracks or cleats.

Like most other Indian coals, the Bokaro coals also contain abundant mineral matter which usually occurs in a disseminated state. The minerals are generally fine grained but coarse grained varieties are not altogether absent. Quartz is the most important syngenitic allogenic mineral and shows irregular outline; micas with lath-like form are less common. Kaolinite and siderite occurring in vermicular and nodular forms respectively are the only authigenic minerals present. Epigenitic minerals occur less frequently.

Syngenitic minerals

Allogenic

Quartz. It is the most abundant mineral component and usually occurs in fine grains in the durains as shown in Plate 12, Figs. 4 and 5 and Plate 13, Fig. 5. The grains are generally subangular to subrounded but angular grains are also met with. This mineral often contains fine accicular inclusions and shows wavy extinction suggesting that it is mostly of metamorphic origin.

In addition to quartz there are some other allogenic components like micas, fragments of quartzite and siltstone which occur scarcely.

Subangular quartzite fragments have been observed to occur in the Kargali and Karo seams. In a specimen from the Kargali seam (KK3/12) a large fragment of fine grained siltstone shown in Plate 14, Fig. 1 has been observed to occur in durain. It is comprised of quartz grains vermicular kaolinite and carbonaceous matter which occupies the interspaces of the framework.

Authigenic

Kaolinite. It is an important member of the authigenic group and is often a prominent constituent of durains of the Kargali and Karo seams. It occurs in fine and coarse grains, the latter being more conspicuous due to their typical vermicular and fibrous form.

Kaolinite is one of the most commonly occurring clay minerals. Montmorillonite and Illite (Hydro mica) are the other important members of this group. Clay minerals are hydrous alluminium silicates formed through the action of continuous succession of processes ranging from hydro-thermal solutions to supergene percolating waters and weathering.

A characteristic feature of the clay minerals is their platy or flaky structure. Owing to their very fine size they are generally difficult to identify in thin sections. Special techniques like chemical, optical and X-ray studies have to be employed for a correct identification. But some compound crystals of Kaolinite and other clay minerals often encountered in sedimentary rocks including coal are large enough to be examined conveniently in thin sections. A compound crystal represents the authigenic variety and is formed as a result of integration of individual flakes by compaction and diagenitic recrystallisation after deposition (Williams et al., 1955, p. 331). Such crystals gradually enlarge in size by this process and often acquire large vermicular form.

Sprunk and O'Donnell (1942) and Mackowski have observed worm-like crystals of kaolinite. A coiled grain of kaolinite is shown in Plate 14, Fig. 2. The entire grain appears to extinguish in two principal directions indicating a radial orientation of the flakes which comprise the grain. A group of kaolinite crystals under crossed nicols is shown in Plate 14, Fig. 3. Two crystals in the upper portion are seen to contain dark rod-like inclusions which may be particles of kaolinite coloured by organic pigment (Carozzi, 1960, p. 102).

Siderite. Siderite is the next important authigenic mineral and is particularly prominent in the Kargali and Bermo seams. Its grains occur scattered in durains and also in some vitrinites. This mineral is a carbonate of iron and is believed to have been formed under swamp and lagoon conditions from iron bearing solutions.

Siderite may occur in small granules or form large nodules. Fresh crystals are grey in colour, but often they take a brown stain of limonite on the surface or at the borders. The nodules vary considerably in size as shown in Plate 14, Fig. 4 and Plate 15, Figs. 1 and 2. Plate 15,

Fig. 1 shows a large nodule exhibiting a fibrous central core tinged brown. Sometimes siderite replaces woody tissue in coal as observed in Plate 15, Fig. 2 where a tracheid showing spiral thickenings is formed of siderite.

Epigenitic Minerals

The only epigenitic component found to occur in these coals is some kind of a clay mineral resembling kaolinite. It occurs in fine prismatic crystals in cracks and cleats and shows weak birefringence. The mineral was probably formed as a result of percolation of solution and subsequent precipitation.

CHAPTER VI

REFLECTANCE OF COAL

The study of reflectance of coal components is receiving an increasing attention these days. This method helps in understanding the physical properties of coal and also its rank.

It was with the discovery of microphotometer by Berek in 1930 (see Stach 1949, p. 158) that coal petrologists became increasingly interested in the quantitative assessment of reflectance. Using the Berek slit-photometer and a dry objective, Hoffman and Jenker (1933) observed that the reflectance increased continuously with the increase of rank. Seyler (1943, 1944, 1949, 1952) extended his observation to a large number of coals of different rank using oil immersion objective for the first time. He has advanced an interesting theory which has attracted considerable attention.

Seyler (1943) stated that the constituents of coal derived from wood or bark, excluding spores, cuticles and resins, have reflectances that vary discontinuously and can be arranged in a fixed series of nine steps in a geometric progression. The reflectance in oil could be represented by the equation $R_o = 0.36 \times 1.36^{N_R}$, where N_R is the number of component, from 1 to 9. The predominant and usually the lowest ulmic component present in the bright coals has been called vitrinite and the highest component, No. 9, is named fusinite. The intervening components are classed as intermediates. Generally only three or four of these components are present in appreciable quantities in any coal. Seyler also postulated that as the coal increased in rank through metamorphism, the components present suddenly mutated to the next higher step. Finally when the limit of metamorphism was reached the coal would consist entirely of component 9, called fusinite. Seyler assumed that the occurrence of several components in a specimen of coal is due to diagenesis or metasomatism.

Seyler's results have initiated considerable interest and several attempts/been made to test the validity of his conclusions.
have

Dahme and Mackowski (1950) and McCartney (1952) have cast doubts on the validity of Seyler's results. Dahme and Mackowski preferred the use of a photocell connected to a galvanometer for measuring the intensity of the reflected beam at the eyepiece. They have not, however, observed a discontinuous variation of reflectance in air. McCartney (loc. cit.) made a detailed investigation of vitrain bands from coals of different rank using Berek slit microphotometer and observed a more or less gradual gradation of reflectance values with change in rank.

The reflectance studies of Huntjens and Krevelen (1954) are specially interesting. Although they agree with Seyler's discontinuous series, "well defined accumulations around Seyler's types Nos. 4 and 5 could not be demonstrated". Sherlock (1951) and Mukherjee (1952) working independently have also observed the stepwise progression of reflectance.

Recent studies by Broadbent and Shaw (1955) and Siever (1957), however, support the views expressed by Dahme and Mackowski (loc. cit.) and McCartney (loc. cit.). Broadbent and Shaw in the light of lumped variance test scrutinized the accumulated reflectance data. As a result of this test and also on the basis of new data these authors proposed that variation in reflectance is more or less continuous with rank and also that "many of the uses of reflectance are independent of the existence of steps or preferences". Using photomultiplier search unit and electronic photometer, Siever (loc. cit.) went a step further and found that not only vitrinite but even the semi-fusinite, fusinite and micrinite demonstrate a continuous process of variation of reflectance with rank.

An interesting part of the reflectance studies, therefore, is to observe the manner of reflectance variation. As no substantial study on the reflectivity of Indian coals has been made so far, it was considered desirable to examine these coals from this point of view. Some reflectance measurements have been made recently by Mukherjee (1961) on a few samples of Jharia XIV seam, which has been affected by igneous intrusion. The present study on the Bokaro coals, therefore, seems to be the first serious attempt in this direction.

Experimental Procedure

The apparatus used in the present investigation was a Berek photometer fitted to a Leitz MOP microscope. As suggested by Seylor, measurements were carried out using a Leitz green filter which gives an approximately monochromatic light. All determinations were made at a low intensity which gives accurate results. The adjustable slit of the photometer and the iris diaphragm of the vertical illuminator were closed down as far as possible so that the light falling on the specimen formed the narrowest possible cone. Excepting the primary calibrations of standards, all measurements were made with an oil immersion objective of 1/10 inch using periplanitic eyepiece of X8 magnification. In this way an over-all magnification of 540 was obtained. The immersion oil used was the cedar oil of refractive index 1.515.

In order to standardize the instrument, the reflectance of sphalerite (supplied by Leitz) was rechecked according to the formula:

$$R_a = \left(\frac{\text{Sin } \theta \text{ sphalerite}}{\text{Sin } \theta \text{ quartz}}\right)^2 \times 4.614$$

where θ sphalerite and θ quartz are the angular settings of the analyser for sphalerite and quartz. The reflectance of quartz in air is taken as 4.614. The results are shown in Table No. 16 from which it is clear that the average observed value of reflectance of sphalerite in air (17.00) is in close agreement with the standard value (16.97).

In the present study sphalerite was used as the standard mineral for measuring reflectance of coal components in oil according to the

TABLE NO. 16: THE REFLECTANCE MEASUREMENTS OF SPHALERITE IN AIR

No. of observation		R_a per cent
1		17.02
2		16.99
3		16.98
4		17.11
5		17.00
6		17.03
7		19.99
8		17.02
9		17.01
10		16.92
	Average	17.00

formula:-

$$Ro = \left(\frac{\text{Sin } \theta \text{ coal}}{\text{Sin } \theta \text{ sphalerite}}\right)^2 \times 5.108$$

where Ro is the reflectance in oil.

The reflectance measurements were made on 25 samples of coal from the Kargali (13 samples), Karo (7 samples) and Kuju (5 samples) seams.

The coal samples were cut into cubes of about 1 inch and polished along the bedding plane as follows:-

1. Preliminary grinding by successively finer grades (80, 220, 400, 600, 800) of carborundum powder.

2. Dry polishing was completed on a polishing machine using emery paper of 1/0, 2/0, 3/0, 4/0 grades.

3. Wet polishing was completed on a thick compressed felt using levigated Goddard's plate powder as the polishing medium.

4. Hand polishing carried on chamois leather.

Results and Discussion

About 50 to 70 readings were made on each sample and six to ten settings were made for each reading. Table No. 17 shows the maximum and minimum reflectance (Ro) for twenty five samples examined. These reflectance percentages are the average values based on measurements made at a number of places. The values of fixed carbon for all the samples and of carbon for seven samples, on dry-ash-free basis, are also recorded in the Table.

A noteworthy feature is that while the minimum reflectance for Kargali coals is generally 0.92 per cent, it is about 1.25 per cent for

TABLE NO. 17: REFLECTANCE MEASUREMENTS IN OIL AND PARTIAL CHEMICAL ANALYSES OF SAMPLES.

S.No.	Sample	Ro per cent minimum	Ro per cent maximum	Fixed Carbon per cent (dry ash free)	Carbon per cent (dry ash free)
	<u>Kargali seam</u>				
1.	S/7, Swang Colliery	0.93	2.35	64.1	87.38
2.	S/9, " "	0.92	3.13	65.7	-
3.	KB7/3, Bokaro Colliery, Quarry No. 7	0.90	2.25	65.4	88.45
4.	KB7/9, " " "	0.92	3.19	66.7	-
5.	KB7/21, " " "	0.91	1.78	66.3	-
6.	KB7/31, " " "	0.92	1.53	66.1	-
7.	KB7/75, " " "	0.92	3.11	67.2	89.46
8.	KB7/76, " " "	0.92	3.15	65.6	-
9.	KB7/84, " " "	0.92	2.26	67.1	-
10.	KB7/96, " " "	0.93	1.76	63.6	-
11.	KB7/102, " " "	0.91	1.67	63.6	-
12.	KB7/109, " " "	0.92	2.79	67.1	84.76
13.	KK3/1, Kargali Colliery, Quarry No. 3	0.92	2.25	65.4	-

TABLE NO. 17: REFLECTANCE MEASUREMENTS IN OIL AND PARTIAL CHEMICAL ANALYSES OF SAMPLES (CONTINUED).

S.No.	Sample	Ro per cent minimum	Ro per cent maximum	Fixed Carbon per cent (dry ash free)	Carbon per cent (dry ash free)
	Karo seam				
14.	KA/2, Karo Plot 'A'	1.25	3.11	78.6	-
15.	DKB/2, Khas Dhori, Quarry No. 4	1.23	3.10	74.1	-
16.	DKB/7, " " "	0.93	2.26	76.7	-
17.	DKT/5, " ", Quarry No. 3	1.26	2.88	71.2	-
18.	PKT/5, Pichri Colliery	0.93	2.24	[illegible]	-
19.	T/1, Turio Colliery	1.18	2.27	-	-
20.	KSK/2, Kalyani Selected Kargali	1.26	3.14	78.8	90.04
	Kuju seam				
21.	WB/K3, Kuju Colliery	0.66	2.73	64.6	-
22.	WB/K4, " "	0.55	1.65	62.1	83.17
23.	WB/M3, Morpa Colliery	0.54	1.26	61.9	82.46
24.	WB/M4, " "	0.67	2.46	61.9	-
25.	WB/H3, Haisagarha Colliery	0.65	1.48	62.2	-

the Karo coals and 0.54 to 0.67 per cent for coals of the Kuju seam. It is also evident from the Table that an increase in the reflectance is generally accompanied by an increase in the respective fixed carbon and carbon percentages. The variation in reflectivity and its relation with fixed carbon and carbon in coals of the three seams is significant. There is no systematic variation in the values of maximum reflectance which vary from 1.26 to 3.19 per cent.

Variation in Reflectance

Although Seyler (1943), Sherlock (1951), Mukherjee (1952) and Huntjens and Krevelen (1954) have observed a stepwise variation in reflectance, it has not been found so by Dahme and Mackowski (1950), McCartney (1952), Broadbent and Shaw (1955) and Siever (1957) who are of the opinion that the variation is more or less continuous. In order to study the manner in which reflectance varies in the Bokaro coals, twelve samples (7 from the Kargali, 3 from the Karo and 2 from the Kuju seams) were examined in detail. The observations were made on all constituents except the resinites, sporinites and cutinites. The results are recorded in Table Nos. 18, 19 and 20. The first column in each Table gives the reflectance in air of a standard sample of sphalerite. Seyler's standard components, their mean reflectance and the mean percentage deviation are also noted in the tables. The deviation per cent may be defined as the difference between the observed values of reflectance and that of the nearest Seyler component expressed as a percentage of the difference

TABLE NO. 18: REFLECTANCES IN OIL FOR COALS OF KARGALI SEAM.

Sample No.	Reflectance of Sphalerite in air (R_a) (per cent)	COMPONENT NUMBER 4	(5a)*	5	6	(6b)*	(7a)*	7	(7b)*	(8a)*	8
S/7	16.99	0.89	1.12	1.24	1.68	1.90		2.28	2.36		
	16.92	0.92	1.13	1.27	1.66	1.86		2.24	2.38		
	17.08	0.92	1.15	1.26	1.62	1.84		2.23	2.36		
	17.04	0.91	1.10	1.25	1.65	1.82		2.26	2.32		
	16.99	0.90	1.11	1.27	1.67	1.85		2.22			
	17.00	0.93	1.13	1.28	1.64	1.83		2.23			
	16.99	0.88	1.18	1.25	1.65	1.82		2.24			
	16.98	0.96	1.14	1.26	1.66	1.87		2.27			
	17.01	0.97		1.29	1.69	1.89		2.25			
		0.94		1.30	1.69			2.29			
		0.93		1.26	1.65			2.23			
		0.92		1.26							
		0.95		1.27							
		0.94		1.26							
		0.94									
		0.92									
		0.93									
		0.96									
		0.94									
		0.92									
KB7/9		0.91		1.29	1.69		2.01	2.24		2.88	
		0.98		1.24	1.65		1.99	2.26		2.91	
		0.93		1.21	1.65		2.02	2.27		2.88	
		0.92		1.23	1.62		1.96	2.23		2.90	
		0.94		1.25	1.69		1.99	2.29		2.86	
		0.95		1.26	1.64		2.00	2.25			
		0.99		1.24	1.65		2.02	2.31			
		0.92		1.22	1.77			2.21			
		0.92		1.27	1.68			2.24			
		0.96		1.24	1.64			2.22			
		0.88		1.29	1.67						
		0.95		1.25	1.63						
		0.91		1.27							
		0.90									
		0.89									
		0.93									
		0.97									
		0.88									
		0.92									

TABLE NO. 18: REFLECTANCES IN OIL FOR COALS OF KARGALI SEAM (CONTINUED).

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER									
		4	(4b)*	(5a)*	5	(6a)*	6	(6b)*	(7a)*	7	8
KB7/31	17.01	0.90		1.19	1.23	1.55					
	16.99	0.89		1.20	1.28	1.52					
	16.97	0.94		1.16	1.22	1.50					
	16.98	0.91		1.20	1.26	1.51					
	16.96	0.98		1.21	1.29	1.59					
	16.97	0.93		1.18	1.24	1.52					
	16.98	0.92		1.19	1.31						
		0.94		1.17	1.22						
		0.97		1.13	1.27						
		0.95		1.17	1.21						
		0.91		1.20	1.27						
		0.90		1.19	1.22						
		0.88			1.22						
		0.89			1.24						
		0.92			1.25						
		0.95									
		0.94									
		0.93									
		0.99									
		0.97									
		0.90									
		0.89									
		0.94									
KB7/75		0.91	1.08		1.22		1.65	1.83	2.08	2.24	3.12
		0.93	1.01		1.25		1.62	1.82		2.21	3.09
		0.92	1.07		1.26		1.58	1.85		2.23	3.12
		0.92	1.06		1.23		1.63	1.82		2.19	3.10
		0.94	1.10		1.20		1.68	1.83		2.26	3.11
		0.91			1.24		1.62			2.23	
		0.92			1.23		1.63			2.31	
		0.93					1.63				
		0.90					1.55				
		0.91									
		0.89									
		0.96									
		0.93									
		0.89									
		0.92									
		0.91									
		0.99									
		0.97									
		0.95									
		0.93									
		0.85									
		0.94									
		0.93									
		0.96									
		0.92									

TABLE NO. 18: REFLECTANCES IN OIL FOR COALS OF KARGALI SEAM (CONTINUED).

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER								
		4	(4b)*	5	(6a)*	6	(6b)*	(7a)*	7	8
KB7/76	16.95	0.96	1.05	1.24	1.47	1.59		1.97	2.19	3.16
	16.94	0.92	1.02	1.23	1.48	1.68		1.96	2.21	3.14
	17.02	0.91	1.04	1.25	1.47	1.62		1.93	2.24	3.13
	17.20	0.90	1.03	1.21		1.61		1.97	2.20	
	17.00	0.91	1.03	1.30		1.64		1.94	2.22	
		0.92		1.29		1.63			2.23	
		0.93		1.24		1.70				
		0.94				1.71				
		0.94				1.65				
		0.93				1.62				
		0.91								
		0.91								
		0.89								
		0.90								
		0.91								
		0.95								
		0.85								
		0.87								
		0.95								
		0.94								
		0.92								
KB7/96		0.93		1.26	1.48	1.66	1.75			
		0.94		1.25	1.50	1.60	1.79			
		0.90		1.23	1.42	1.69	1.74			
		0.91		1.29	1.46	1.63	1.76			
		0.92		1.21	1.49	1.70	1.86			
		0.92		1.30	1.44	1.62	1.73			
		0.90		1.28	1.47	1.64	1.75			
		0.93		1.25		1.59				
		0.94		1.22						
		0.89		1.26						
		0.96		1.25						
		0.94		1.22						
		0.93		1.34						
		0.92		1.24						
				1.27						
				1.29						
				1.25						
				1.24						
				1.21						
				1.26						
				1.24						

TABLE NO. 18: REFLECTANCES IN OIL FOR COALS OF KARGALI SEAM (CONTINUED).

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER						
		4	(4b)*	5	(6a)*	6	7	8
KB7/102	17.00	0.90	1.05	1.23	1.43	1.65		
	17.02	0.89	1.05	1.20	1.49	1.70		
	17.02	0.91	1.07	1.22	1.48	1.70		
	16.98	0.94	1.04	1.24	1.50	1.68		
	17.01	0.92	1.04	1.25	1.49	1.60		
		0.96	1.07	1.27	1.43	1.68		
		0.90		1.20	1.47	1.65		
		0.91		1.24		1.68		
		0.90						
		0.89						
		0.93						
		0.92						
		0.91						
		0.94						
		0.92						
		0.92						
		0.91						
		0.88						
		0.87						
		0.87						
Mean value	17.00	0.92		1.25		1.64	2.24	3.14
Seyler's figure		0.92		1.26		1.64	2.23	3.11
Deviation per cent		0		2.29		0	1.69	3.46

* Components which do not correspond with those of Seyler but lie close to them.

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER 4	5	(6a)*	6	(7a)*	7	(7b)*	(8a)*	8
KA/2	16.99		1.27	1.49	1.64	2.01	2.29		2.72	3.10
	16.98		1.24	1.45	1.64	2.00	2.23		2.71	3.14
	17.10		1.30	1.46	1.65	1.99	2.28		2.70	3.09
	17.08		1.26	1.47	1.73	1.98	2.27		2.76	3.10
	17.06		1.24	1.51	1.62	2.06	2.30		2.72	3.12
	17.07		1.21	1.69	1.66	1.93	2.24			3.12
			1.20		1.63	2.00	2.21			
			1.28		1.69		2.25			
			1.24		1.68					
			1.29		1.64					
			1.22							
			1.27							
			1.26							
			1.31							
			1.24							
			1.25							
			1.26							
			1.23							
PKT/5			1.29	1.45	1.66	1.96	2.21			
			1.30	1.50	1.67	1.94	2.23			
			1.25	1.49	1.63	1.98	2.27			
			1.28	1.47	1.63	2.00	2.24			
			1.24	1.42	1.64	1.95	2.25			
			1.27	1.45	1.69	1.97	2.20			
			1.22		1.65	1.94	2.29			
			1.26		1.62					
			1.23		1.70					
			1.29		1.63					
			1.24		1.65					
			1.27		1.64					
			1.28		1.61					
			1.30		1.65					
			1.31							
			1.26							
			1.28							
			1.23							
			1.24							
			1.29							
			1.24							
			1.22							

TABLE NO. 19: REFLECTANCES IN OIL FOR KARO MEASURE COALS (CONTINUED).

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER 4	(4b)*	(5a)*	5	6	(7a)*	7	8
T/1	17.03			1.15	1.24	1.63	1.90	2.28	
	17.01			1.18	1.21	1.65	1.99	2.27	
	17.01			1.19	1.28	1.67	1.98	2.28	
				1.20	1.25	1.64	2.00	2.23	
				1.17	1.26	1.62	1.97	2.24	
					1.26	1.69	2.06		
					1.23	1.63	1.94		
					1.21	1.62			
					1.28	1.70			
					1.30	1.65			
					1.26				
					1.22				
					1.24				
					1.24				
					1.21				
					1.31				
					1.29				
					1.26				
					1.24				
					1.23				
					1.26				
					1.22				
Mean value	17.06				1.26	1.65		2.25	3.11
Seylor's figures		0.92			1.26	1.64		2.23	3.11
Deviation per cent		-			0	2.65		3.45	0

TABLE NO. 20: REFLECTANCES IN OIL FOR COALS OF THE HUJU SEAM.

Sample No.	Reflectance of Sphalerite in air (Ra) (per cent)	COMPONENT NUMBER								
		2	(2b)*	3	(3b)*	4	(4b)*	5	(6a)*	6
WB/H3	17.11			0.62	0.75	0.96	1.12	1.26		
	17.09			0.64	0.74	0.92	1.09	1.22		
	16.99			0.69	0.71	0.93	1.08	1.26		
	17.02			0.68	0.79	0.91	1.14	1.27		
	17.01			0.66	0.72	0.95	1.11	1.20		
	16.99			0.60	0.78	0.92				
	17.00			0.65	0.70	0.93				
	17.01			0.66		0.90				
				0.66		0.87				
				0.63		0.89				
				0.67		0.93				
				0.62		0.99				
				0.68		0.98				
				0.69		0.90				
				0.64						
				0.62						
				0.70						
				0.65						
				0.67						
WB/H4			0.58	0.63	0.73	0.89		1.28	1.46	1.66
			0.55	0.68	0.79	0.88		1.23	1.49	1.67
			0.60	0.71	0.77	0.91		1.29	1.42	1.63
			0.59	0.68	0.74	0.94		1.26	1.51	1.68
			0.54	0.64	0.80	0.90		1.25	1.48	1.64
			0.60	0.65	0.76	0.90		1.30		
			0.59	0.67		0.89				
			0.56	0.64		0.93				
			0.59	0.69		0.96				
			0.58	0.66		0.92				
				0.62		0.89				
				0.63		0.90				
				0.62						
				0.64						
				0.65						
				0.69						
				0.63						
Mean value	17.03			0.65		0.91		1.26		1.65
Seyler's figures				0.67		0.92		1.26		1.64
Deviation per cent				6.25		4.00		0		2.65

* Components which do not correspond with those of Seylor but lie close to them.

between the two components between which the observed value lies. Several reflectance values which do not correspond to Seyler's components but lie close to these have been shown in the respective columns and are marked with an asterisk (*). The results of reflectance measurements of the Kargali, Karo and Kuju seams are represented as bar diagrams in Figs. 18 to 21 which bring out the variation in a clear way.

There is a definite tendency for reflectance values to cluster round certain discrete peaks, the number of which usually vary from four to eight. The deviation per cent generally is between 2 to 3 which shows that in the majority of cases the scattering round the respective means is not pronounced and this is evident from the bar diagrams also. A notable feature is that while the majority of peaks have their mean reflectance values remarkably identical with those given by Seyler to his discrete components, there are others - the secondary peaks - which form distinct groupings in-between the primary peaks.

The seconday peaks are so conspicuous and persistent that their presence cannot be ignored. These have also been noted by Huntjens and Krevelen (loc. cit.), who believe that "the spread in results of reflectance measurements on a given vitrinite may be due to: (a) variability of the refractive index, which may be caused by infiltration of 'resinite' into the vitrinite, or by anisotropic effects; (b) an increase in the absorptive index, owing to diffusion of light". An observer (F) working with Seyler (1952) has also noted several secondary peaks but no explanation has been offered for the scattering.

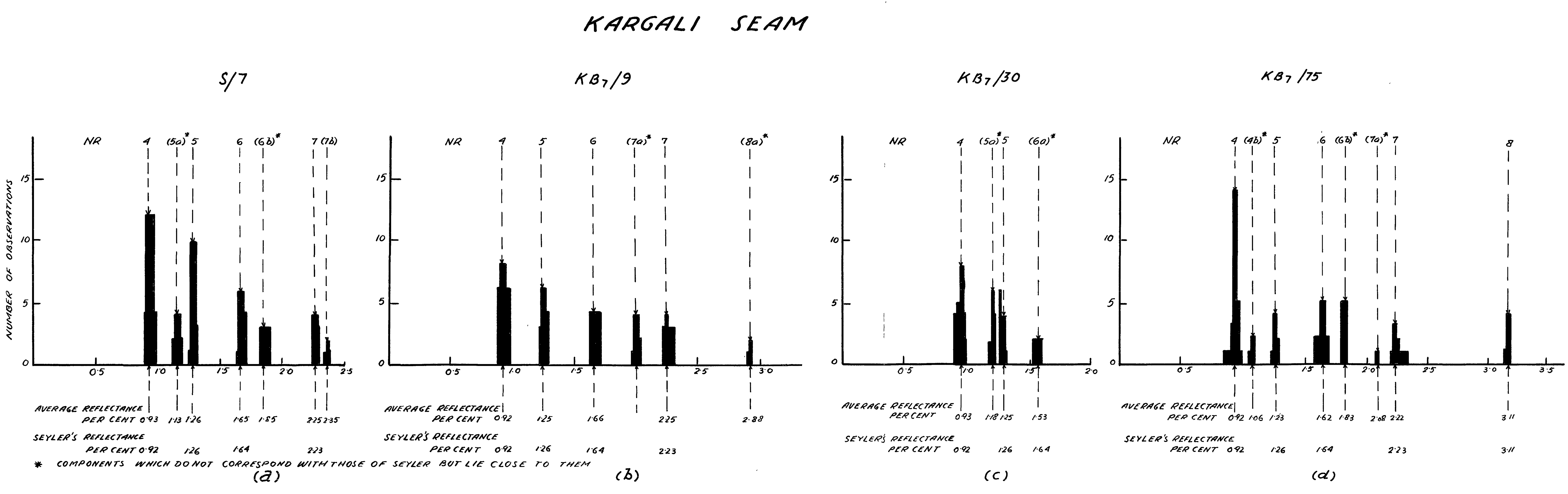

FIG. 18. REFLECTANCE (R_0) VARIATION IN SOME COALS OF THE KARGALI SEAM FROM SWANG AND BOKARO COLLIERIES.

KARGALI SEAM

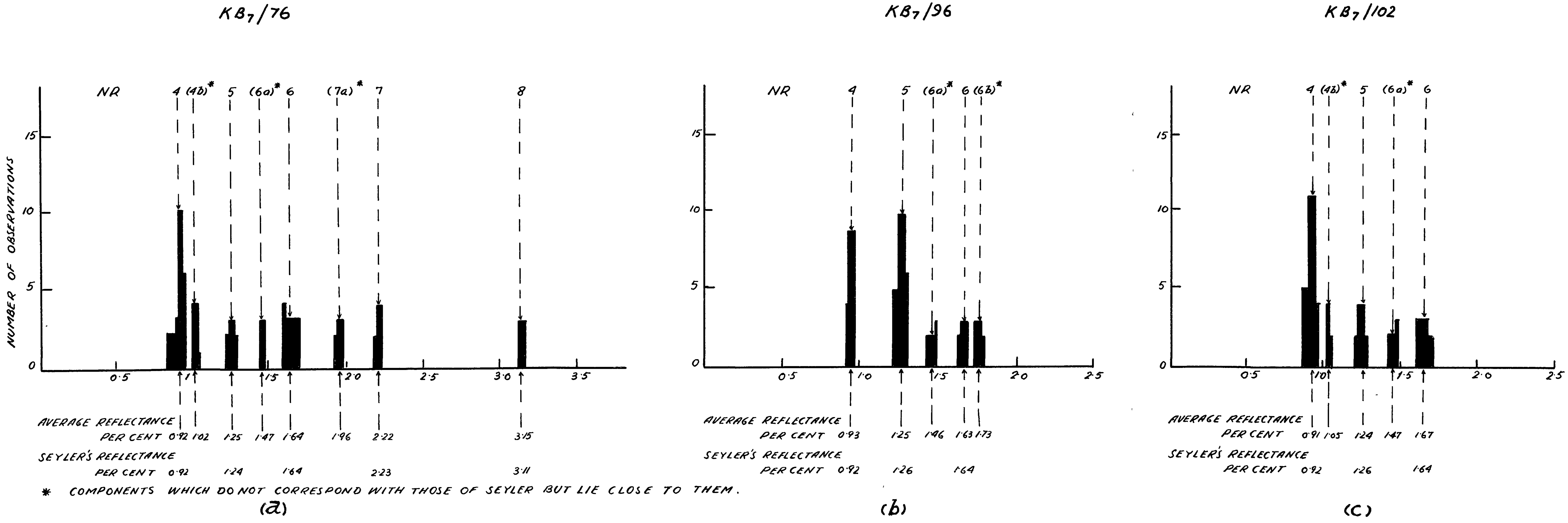

FIG. 19. REFLECTANCE (R_0) VARIATION IN SOME COALS OF THE KARGALI SEAM FROM BOKARO COLLIERIES.

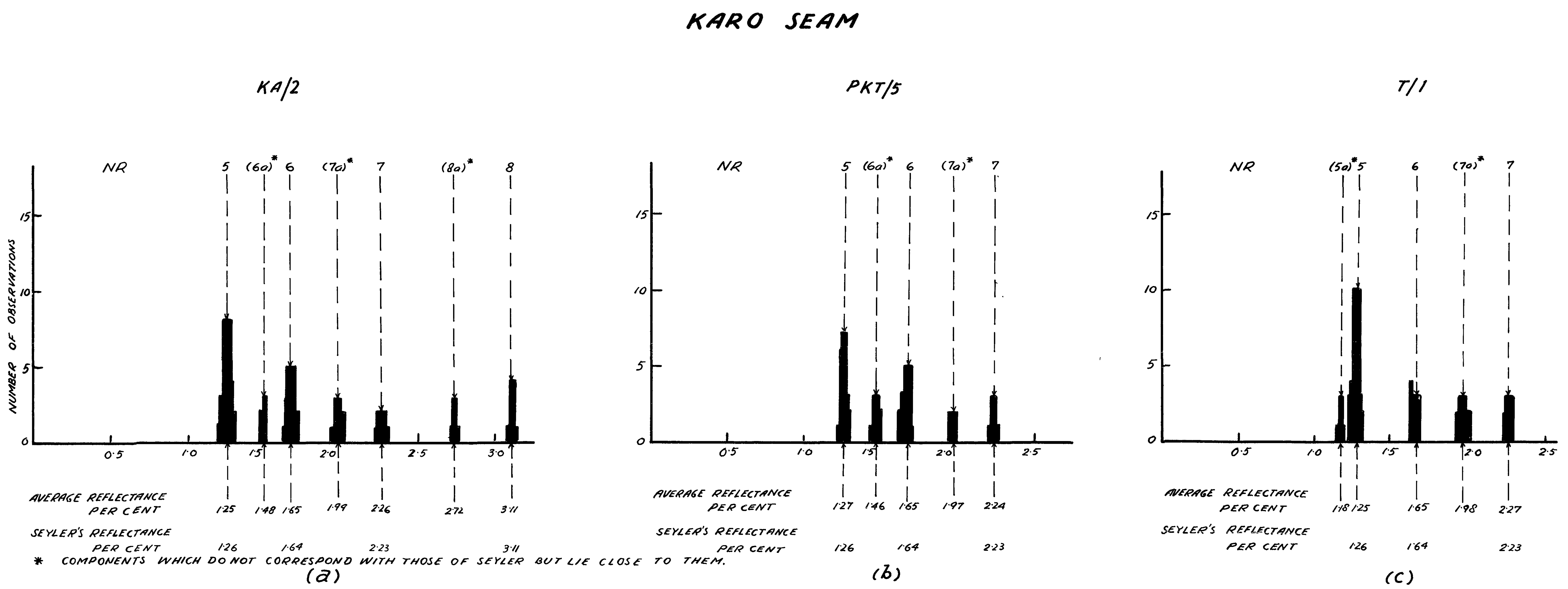

FIG. 20. REFLECTANCE (R_o) VARIATION IN SOME COALS OF THE KARO MEASURES.

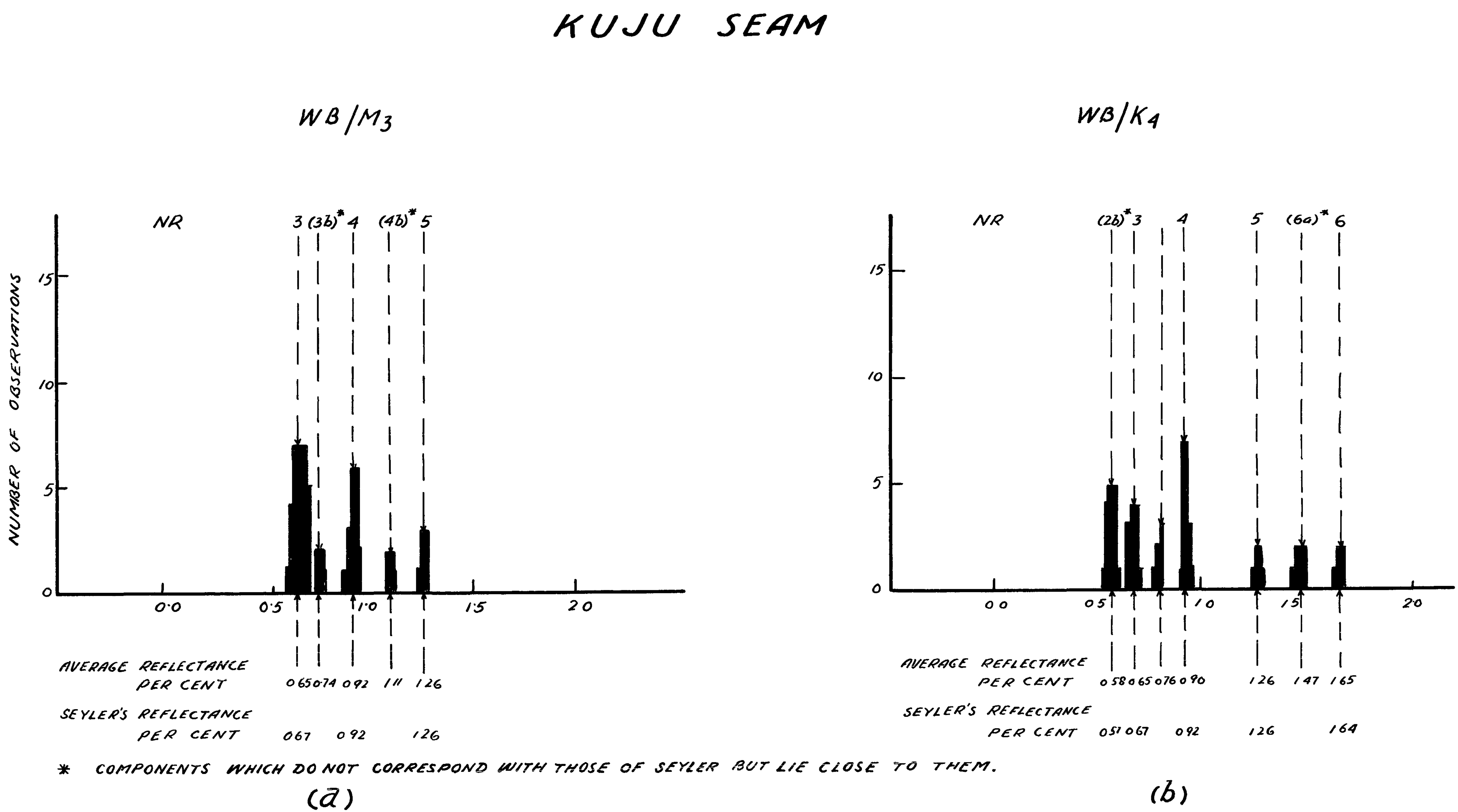

FIG. 21. REFLECTANCE (R_0) VARIATION IN SOME COALS OF THE KUJU SEAM.

An interesting point about the secondary peaks is that these are prominent between lower components viz. Nos. 4 to 7, which evidently represent the vitrinite and first few intermediates. The vitrinite forming tissues have been often observed impregnated with peaty solutions which substantially affect their translucency and thereby mask or exaggerate their power of reflection. The reflectance values so obtained are different and do not represent the vitrinites truly. The result is that various irregularly spaced subsidiary or secondary peaks are observed.

An overall examination of the distribution of reflectance, however, shows that while the evidence is largely in favour of Seyler's grouping hypothesis, there are a few cases as shown in Fig. 18(a), (d), (e) and Fig. 19(a) in which secondary peaks are more closely spaced. It is difficult to say exactly whether the variation in reflectance is stepwise or more or less continuous in these cases. In a delicate problem of reflectance measurements, the comparison of results is based entirely on human judgement which is not a precise criteria. A satisfactory solution of the problem may be obtained if an appropriate statistical test is applied to the given data.

Lumped Variance Test for Grouping

Broadbent and Shaw (1955) applied for the first time 'lumped variance test' to the study of coal reflectance. This test helps to know if the given reflectance values have a tendency to cluster round certain peaks.

The mathematical model proposed by Seyler for reflectance data is:-

$$R = \beta + 2\delta N_R + \varepsilon$$

where R denotes the logarithm of the measurement of reflectance in oil, β and 2δ are constants with values log. 0.26 and log. 1.36 respectively, N_R is an integer between 0 and 9 and ε is the error of measurement. The lumped variance test is designated by the formula:-

$$S^2 = \sum_{i=1}^{n} Zi^2/n$$

where n refers to the number of observations made and Zi corresponds to i th observation. S^2 is therefore the average squared distance of the data from the peaks indicating whether the values tend to cluster round the peaks. The value is zero if observations are precisely at the peak, low if they cluster closely, and high if they do not cluster.

As an alternative to the Seyler's model, Broadbent and Shaw (loc. cit.) proposed the rectangular hypothesis according to which there is a smooth distribution of S^2 values with no evidence of clustering at the peaks. It was further suggested that if the variance of error (ε) increases, even though there is stepwise variation, S^2/δ^2 will increase and there will be a smooth distribution of S^2 values.

According to this test if S^2/δ^2 is not significantly different from 1/3 the model is rejected i.e. the data is compatible with rectangular hypothesis. If S^2/δ^2 is significantly smaller than 1/3 the model is accepted. The critical values of S^2/δ^2 at the 5 per cent and 1 per cent levels of significance, as given by Broadbent (1955), are listed below:

No. of observation	Significance level	
	5%	1%
20	0.114	0.178
25	0.235	0.194
35	0.250	0.216
40	0.256	0.224
45	0.260	0.229
55	0.267	0.239
60	0.270	0.244
65	0.272	0.247
75	0.276	0.263
80	0.279	0.266

The lumped variance test was applied to the data shown in Table Nos. 18, 19 and 20. The results are recorded in Table No. 21 where 5 per cent level of significance is used in order to determine whether or not the Seyler's model is acceptable.

TABLE NO. 21: RESULTS OF VARIANCE TEST FOR GROUPING

S.No.	Sample Nos.	No. of observation	S^2/δ^2	Conclusion, model is
1.	S/1	77	0.103	accepted
2.	KB7/9	71	0.150	accepted
3.	KB7/31	55	0.182	accepted
4.	KB7/75	70	0.194	accepted
5.	KB7/76	60	0.153	accepted
6.	KB7/96	58	0.183	accepted
7.	KB7/102	49	0.184	accepted
8.	KA/2	64	0.184	accepted
9.	PKT/5	54	0.142	accepted
10.	T/1	49	0.188	accepted
11.	WB/M3	51	0.179	accepted
12.	WB/K4	62	0.181	accepted

From the Table it is evident that S^2/δ^2 for each sample is significantly less than 1/3 suggesting that Seyler's model holds good. Even in the few cases shown in Fig. 18(a), (d), (e) and Fig. 19(a) where visual judgement shows some doubt about the validity of grouping hypothesis, S^2/δ^2 is significantly less (0.103, 0.153 and 0.183), confirming thereby that the data is incompatible with rectangular hypothesis and follows the Seyler's model.

Petrological Analysis and Somatic Variation

The vitrinite and opaque constituents like fusinite, semi-fusinite and micrinite are the two main attributes which determine whether a coal is bright or dull. The reflectance studies have shown that a coal is comprised of a set of petrological components each of which has a varying frequency depending upon the rank and type of coal.

In order to study the frequency distribution or the somatic variation of the various components and to find out the variation in reflectance with change of rank, six samples, two each from the Kuju, Kargali and Karo seams, were selected for quantitative petrological analysis using Dollar's integrating stage. The results of the analysis are recorded in Table No. 22 and histograms showing frequency variation are shown in Fig. 22. The component having the minimum reflectance generally shows peakedness in the bright coals as it represents vitrinite. With the increase in rank the next higher component shows peakedness. Thus in order of increasing rank in coals of the Kuju, Kargali and Karo seams peakedness is shown by No. 3, No. 4 and No. 5 components respectively. In the durainy coals, however, where intermediates acquire prominence, peakedness is not so well marked and the first two or three components generally constitute the bulk of the coal. Thus on the basis of frequency distribution of petrological components, or Somatic pattern, the rank of a coal can be easily ascertained.

TABLE NO. 22: REFLECTANCE PERCENTAGE OF SOME TYPICAL COALS.

Sample No. and type of coal	Reflectance Ro (per cent)	N_R	Description of component	Per cent (By Volume)	Calculated per cent of standard component (By Volume)
WB/H3 — <u>Kuju Seam</u>					
Vitrainy (Bright) coal	0.65	3	Vitrinite	78.3	81.9
	0.74	(3b)*		2.3	
	0.92	4	1st Intermediate	12.8	13.4
	1.11	(4b)*		2.1	
	1.26	5	2nd "	4.5	4.7
					100.0
WB/K4 — <u>Kuju Seam</u>					
Durainy coal	0.57	(2b)*		2.7	
	0.65	3	Vitrinite	30.8	33.9
	0.76	(3b)*		4.5	
	0.90	4	1st Intermediate	42.1	46.5
	1.26	5	2nd "	5.0	5.6
	1.47	(6a)*		2.2	
	1.65	6	3rd "	12.7	14.0
					100.0
KB7/75 — <u>Kargali Seam</u>					
Vitrainy (Bright) coal	0.92	4	Vitrinite	76.5	83.8
	1.07	(4b)*		3.5	
	1.23	5	1st Intermediate	5.3	5.9
	1.62	6	2nd "	4.8	5.5
	1.83	(6b)*		2.9	
	2.08	(7a)*		2.8	
	2.24	7	3rd "	3.1	3.5
	3.10	8	4th "	1.1	1.3
					100.0
KB7/96 — <u>Kargali Seam</u>					
Durainy coal	0.93	4	Vitrinite	39.4	41.9
	1.25	5	1st Intermediate	42.8	45.6
	1.46	(6a)*		1.6	
	1.63	6	2nd "	11.7	12.5
	1.76	(6b)*			
					100.0

TABLE NO. 22: REFLECTANCE PERCENTAGE OF SOME TYPICAL COALS (CONTINUED).

Sample No. and type of coal	Reflectance Ro (per cent)	N_R	Description of component	Per cent (By Volume)	Calculated per cent of standard component (By Volume)
PKT/5 — Karo Seam					
Vitrainy (Bright) coal	1.27	5	Vitrinite	72.1	79.2
	1.46	(6a)*		3.6	
	1.65	6	1st Intermediate	11.4	12.5
	1.97	(7a)*		5.3	
	2.24	7	2nd "	7.6	8.3
					100.0
KA/2 — Karo Seam					
Durainy coal	1.25	5	Vitrinite	55.7	59.3
	1.48	(6a)*		2.2	
	1.65	6	1st Intermediate	32.4	34.8
	1.99	(7a)*		3.1	
	2.26	7	2nd "	3.1	3.4
	2.72	(8a)*		1.2	
	3.11	8	3rd "	2.3	2.5
					100.0

* Components which do not correspond with those of Seyler but lie close to them.

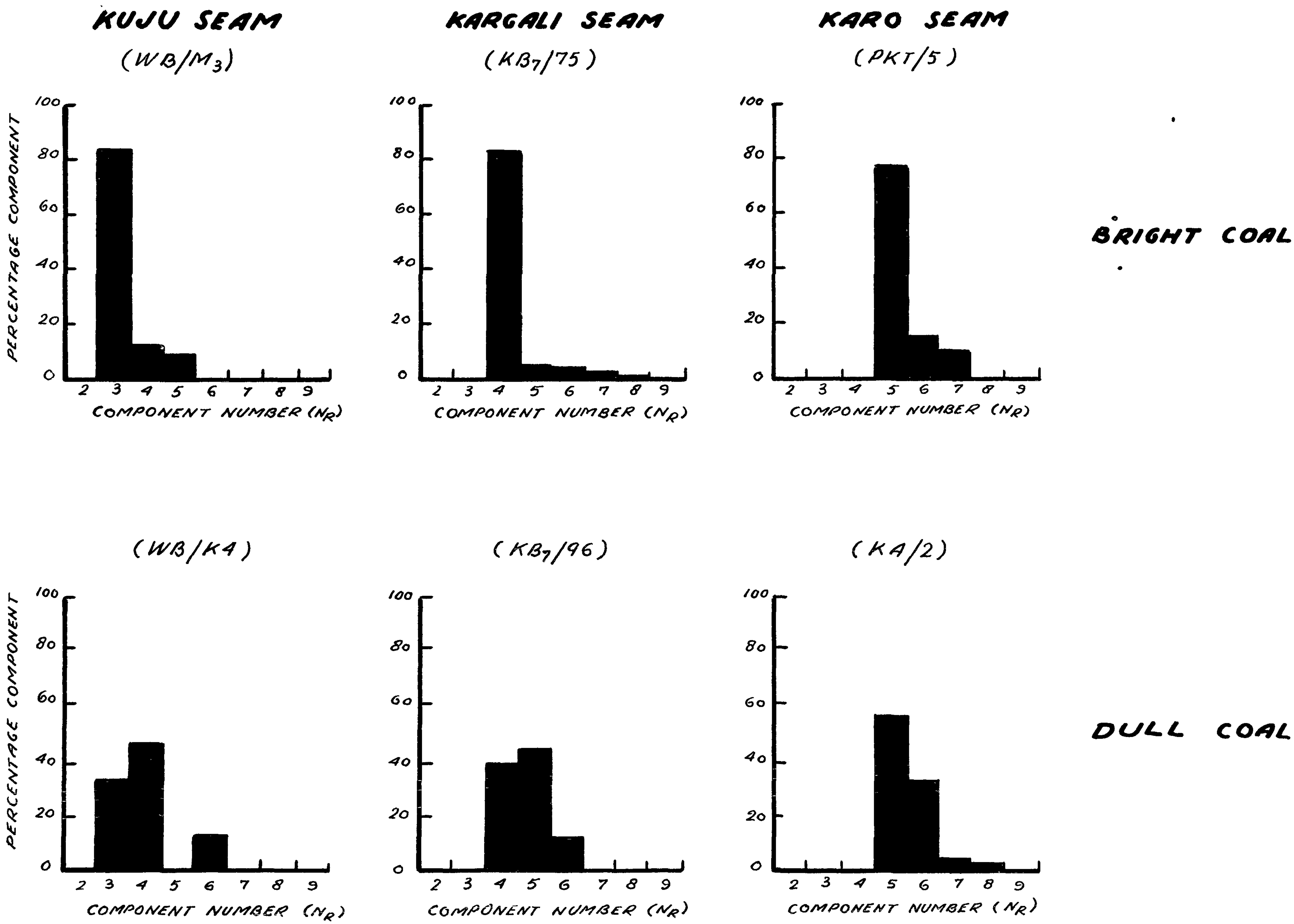

FIG. 22. FREQUENCY DISTRIBUTION OF COMPONENTS (N_R) IN SOME TYPICAL 'BRIGHT' AND 'DULL' COALS OF THE KUJU, KARGALI AND KARO SEAMS.

Inspite of the best efforts it could not be possible to differentiate exactly between the various opaque constituents especially the semifusinite and fusinite and, therefore, these are designated as 'Intermediates'. Siever (1957), however, has been able to differentiate between micrinite, semifusinite and fusinite and has given a range of reflectance for each. His values, however, overlap and it is doubtful if these can be of any practical utility.

It is now being recognized that reflectance can play an important role in the classification of coals and several attempts have been made in this direction in the recent years (Broadbent and Shaw, 1955; Siever, 1957). The studies in the reflectivity of coal have a fertile field for research in this country as no substantial contributions in this direction have been made till now.

SUMMARY AND CONCLUSIONS

The Bokaro coalfield lies between 23°45' and 23°50' N. Lat. and 85°27' and 86°03' E. Long. in the district of Hazaribagh, Bihar. It covers an area of about 220 square miles and includes a narrow belt of Gondwanas extending 40 miles from east to west and 6 to 10 miles from north to south.

The Gondwana rocks comprised of the Talchir, Damuda and Panchet series, rest on and are surrounded by the Archaeans. The Talchirs which underlie the Barakars are poorly developed and occur in thin and narrow outcrops near the eastern and western extremity. The Barakars cover the greatest part of the field and the younger group of rocks occur in narrow patches mostly around the Lugu hill. While the southern boundary of the coalfield is faulted, the northern, eastern and western limits show mixed effects of denudation and faulting. Faults are of common occurrence with the result that the strata are much disturbed and the stratigraphy is complex at various places.

The Barakars are the chief coal-bearing strata in the area and these have been classified by Fermor into four subdivisions. Eight productive coal seams, five belonging to the East Bokaro coalfield and three to the West Bokaro coalfield, are known to occur. The various coal seams in their downward succession are:-

East Bokaro Coalfield			West Bokaro Coalfield		
12-foot A seam	..	12 ft.	Kuju seam	..	40 ft.
Jarangdih seam	..	20 ft.	No. XI seam	..	30 ft.
Kargali seam	..	100 ft.	No. X seam	..	20 ft.
Bermo seam	..	45 ft.			
Karo seam	..	80-100 ft.			

This coalfield has been selected for the present investigation as very little information is available regarding the chemical and microscopical characters of the coals. All the eight seams have been studied in respect of their geology, chemical characters and petrological nature.

The field work was conducted in the winter season of 1957 and again in November, 1958. Thirty collieries were visited and 314 representative samples of the various seams were collected.

The geology of the Karo measures in the type area has been discussed in detail. The Top and Bottom Karo are the two main seams of the Karo measures having a general east-west strike. In the eastern part, the Karo measures are affected by a number of faults as a result of which the direction of the strike has abruptly changed at several places. The seam outcropping to the east of the Teesri nala fault has been designated as Eastern Karo seam. A narrow coal-bearing strata has been found to occur near Makoli in the East Bokaro coalfield. It includes five coal seams of total thickness of 50 ft. These seams probably underlie the main seams of the Karo measures and belong to the third subdivision of the Barakars as classified by Fermor.

The author has reported the occurrence of clastic dykes cutting across the Kargali seam in the Kargali and Bokaro collieries for the first time. No such dykes have been reported from this coalfield by the previous workers. Petrographically the dyke rocks show enormous variation in their composition. Quartz is the dominant detrital component with finely crystalline siderite as the chief cement. Replacement of detrital grains by the cement is an important feature of all the dyke rocks. It has been tentatively suggested that the slurry constituting these rocks was injected into the pre-existing cracks of the coal seam from the top.

In order to assess the chemical properties of the various coals, chemical investigation has been carried out on 161 selected samples. Besides the proximate and ultimate analyses, determinations of calorific value, caking and B.S. Swelling index and in certain cases of Gray-King assay and Hardgrove Grindability tests have also been made.

The Kargali coals are low in moisture. Coals in the Swang and Bokaro collieries lying in the western part of East Bokaro are on an average low to medium ash (14.1 to 16.0 per cent), but in the Kargali and Dhori collieries which lie in the eastern part, the coals generally are medium to high ash (average 19.0 to 28.0 per cent). There is a marked regional variation in the volatile contents from Dhori in the east (average 30.4 per cent d.a.f.) to Swang in the west (average 36.1 per cent d.a.f.) in a stretch of about 10 miles. On the whole, these coals may be regarded as of medium to high volatile (average 29.0 to 33.0 per cent, d.a.f.) grade. A good portion of these coals may be referred to Grade I category (calorific value, on d.a.f. basis, varying from 14,726 to 16,221 B.th.u/lb). While 77 per cent of the coke button types indicate a good caking coal, 20 per cent show poorly caking coal and the remaining 3 per cent represent non-caking type. It is observed that fairly swelling type of coke buttons (C_f) with good cell structure and metallic lustre are obtained from coals having an average volatile matter of 34.9 per cent (d.a.f.). The results of caking and B.S. Swelling index and also the nature of coke buttons show that the coals are generally well within the range of good coking coals.

Ash varies widely in coals of the Karo measures (from 9.8 to 29.9 per cent). The Top Karo coals are of medium volatile grade (24.2 to 32.2 per cent, d.a.f.) and those of the Bottom Karo and Eastern Karo are low to medium volatile (20.7 to 27.7 per cent, d.a.f.). The coking properties of the Top Karo and Eastern Karo show that these coals are of fairly coking type. This is further confirmed by the Gray-King Carbonization test. The HGI (Hardgrove Grindability Index) for coals of the Karo measures varies from 60 to 78, suggesting that these can be easily pulverised and can be locally used in the manufacture of soft coke.

The coals of the 12-foot and Jarangdih seams show more or less similar chemical characters. These are on the whole high volatile, medium rank coals. Coals of the Bermo seam contain moderately high ash.

The Kuju seam is the only important coal seam of the West Bokaro coalfield differing in several important respects from those of the Kargali and Karo. The average moisture in coals of the Kuju seam is 1.4 per cent and ash content is low to medium (7.2 to 17.2 per cent) increasing in certain sections, especially in those of the Haisaghara colliery (24.3 to 30.2 per cent). These are high volatile coals with volatile matter (d.a.f.) ranging from 32.8 to 38.6 per cent. On the whole these coals cannot be regarded as good coking coals; these are best suited for steam raising, gasification or long flame heating.

The Karo coals are slightly higher in rank (average C: 89.0 per cent on d.a.f.) than the Kargali coals (average C: 87.5 per cent on d.a.f.), but those of the Kuju seam are comparatively lower in rank (average C: 82.0 per cent on d.a.f.).

Coals of the No. X and No. XI seams contain fairly high ash (16.0 to 23.7 per cent) and are of medium volatile grade (23.2 to 30.3 per cent d.a.f.).

The microscopic study is based on an examination of 300 thin and 25 polished sections. The technique followed in preparing thin sections was more or less the same as adopted by Dr. Ganju. The thin-section study reveals that for the most part vitrinite is made up of woody tissue often exhibiting well preserved structure. Medullary ray cells are fairly abundant. A characteristic feature of some woods is the presence of large quantity of brown fragmental and opaque finely granular matter in the cells. The decomposition of cell walls by the agency of micro-organisms has been considered as the chief cause for the formation of both kinds of material. Micro-deformation and bogen structure have been observed in the vitrinite bands. The bark tissue occurs less commonly and shows alternating bands of thick-and thin-walled cells. Fusinite often shows well preserved woody structure.

Three types of durain have been observed. In the fibrous durain shreds and streaks of vitrinite are dominant and tend to have a bedded pattern. Micrinite, mineral matter, resins and microspores have also contributed to its formation. Durain produced as a result of degradation is made up of decomposed fragments and bits of vitrinite. In addition it includes resin bodies, micrinite, mineral matter and microspores in varying proportion. Megaspores on the whole are scarce. In the third type of durain the opaque attritus dominates. Vitrinite is subsidiary and occurs in thin streaks or fibres.

Mineral matter forms a dominant constituent of these coals. It occurs in a finely divided state or in large grains disseminated in durain. Allogenic minerals are more prevalent than authigenic; epigenitic minerals are scarce. Finely granular quartz constitutes the bulk of the allogenic minerals. Micas and rock fragments of quartzite and siltstone are less prominent. Among authigenic minerals Kaolinite in its typical vermicular form is conspicuous. Siderite which generally occurs in nodules is quite prominent and is often fairly abundant.

That the debris containing the plant fragments was transported prior to its deposition is proved by the disseminated nature of the mineral constituents and their dominantly detrital character.

Reflectivity measurements were made on 25 selected samples of the Kargali, Karo and Kuju seams in order to confirm the rank variation in the coals and to study the variation in reflectance. The reflectivity study reveals rank variation in the coals of the Kuju, Kargali and Karo seams, the average reflectance percentage (Ro) of each being 0.67, 0.92, 1.25 respectively. There is a definite evidence of reflectance values (Ro) to cluster round certain regularly spaced peaks which are in close conformity with those observed by Seyler. Several secondary peaks particularly between component Nos. 4 to 7 have also been observed. The validity of grouping hypothesis is further confirmed by the lumped variance test. The somatic pattern in some typical bright and dull coals has been studied. While the component (N_R) of minimum reflectance constitutes the bulk of the bright coals, the first two or three components acquire prominence in the dull coals.

EXPLANATION OF PLATES

PLATE 1

Fig. 1. An outcrop of the Bottom Karo seam showing contortions and plications.

Southern bank of the Damodar river near Pichri colliery.

Fig. 2. Lower portion of Middle clastic dyke in the worked-out Quarry No. 2

Kargali colliery, Quarry No. 2.

Microphotographs of clastic dykes

(All figures are from thin sections)

PLATE 2

Fig. 1. Limonitic sandstone showing quartz as the chief detrital constituent. The framework is disrupted and the interspaces are filled with limonitic cement.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_1. (X 54)

Fig. 2. Sideritic sandstone showing disrupted framework. Quartz forms an essential detrital component and shows much variation in shape and roundness. A deeply corroded grain is seen in the lower right-hand side. Finely crystalline siderite forms the chief cement.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D2. (X 54)

Fig. 3. Dyke rock showing an abundance of sideritic cement. The framework is disrupted. The contacts per grain being exceedingly low.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_3. (X 54)

Fig. 4. Sideritic sandstone showing quartz and micas as the main constituents of the framework. In the upper left-hand and lower right-hand sides elongated laths of muscovite are bent around the quartz grains.

Western dykes, Kargali colliery, Quarry No. 2, Specimen No. K_2D_4. (X 95)

PLATE 3

Fig. 1. A general view of the sideritic sandstone showing subrounded to angular grains of quartz and flakes of mica. Two laths of muscovite lying in the top left-hand and lower right-hand sides have been torn apart along the cleavage planes.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_2. (X 54)

Fig. 2. The same general features as in Fig. 1. The muscovite piece in the left-hand centre is frayed and the flakes are slightly bent at the extremities. A recrystallised piece of biotite lies near the lower right-hand corner.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_2. (X 54)

Fig. 3. Dyke rock in which fragments of coal also constitute the framework. Finely granular siderite forms the cementing material.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_4. (X 54)

Fig. 4. A general view of the dyke rock under crossed nicols. Coal fragments occur in the interspaces. Crystalline nature of sideritic cement is conspicuous.

Western dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2D_4. (Crossed nicols, X 54)

PLATE 4

Fig. 1. Siderite rich clastic rock in which the proportion and size of quartz and other detrital constituents is considerably reduced. The detrital grains show corroded outlines.

Middle dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2S. (X 54)

Fig. 2. A general view of the dyke rock showing an advanced stage of replacement. Quartz and micas occur as vestiges. Finely granular, crystalline siderite predominates. The rock may be called an ironstone.

Eastern dyke, Kargali colliery, Quarry No. 2, Specimen No. K_2E. (X 54)

Fig. 3. The general characters are similar to those shown in Fig. 2. Detrital constituents are much reduced in size and occur as remnants.

Clastic dyke, Kargali colliery, Quarry No. 1, Specimen No. K_1D. (X 54)

Fig. 4. Siderite rich clastic rock showing subangular to fairly corroded particles of quartz as the chief detrital constituents, mica flakes are scattered and finely granular siderite forms the cement.

Clastic dyke, Bokaro colliery, Quarry No. 7, Specimen No. KB_7D. (X 54)

Megascopic characters of coal

PLATE 5

Fig. 1. A representative block of coal from the Kargali seam showing closely spaced bands of vitrain. Durain is dull and hard.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/5. (About $\frac{3}{4}$ the natural size)

Fig. 2. A typical specimen of coal from the Top Karo seam showing sparsely spaced thin streaks of vitrain. Durain which is dominant is hard, granular and compact.

Top Karo seam, Pichri colliery, Sample No. PKT/4. (About $\frac{3}{4}$ the natural size)

Microscopic characters of coal

(All figures are from thin sections)

PLATE 6

VITRINITE

A. Woody tissue

Fig. 1. A tangential section of wood characterized by closely spaced tracheids. Pale coloured oval resins occur abundantly and often compress the surrounding tracheids. Medullary ray cells and chains of pits are also noticed. The infilling resinous substance of ray cells often encloses gas bubbles and opaque matter.

Kuju seam, Kuju colliery, Sample No. WB/K3. (X 170)

Fig. 2. A fragment of wood cut longitudinally and showing thin fibres along the left-and right-hand margins. In the right-hand side, the fibre walls show rows of pits.

Kuju seam, Morpa colliery, Sample No. WB/M2. (X 125)

Fig. 3. A longitudinal section of woody tissue showing pale coloured compressed and contorted cells with the lumens filled with an opaque matter. Often the cells are inrolled, forked and swollen at the ends. In the cells which are not fully compressed, the lumens contain pale granular material as shown in a cell in the lower left-hand side.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/2. (X 340)

Fig. 4. A tangential section of wood characterized by an abundance of oval medullary ray cells filled with pale resinous substance which often encloses gas bubbles. The cells are usually constricted in the central part and bulged out at one or both ends.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/4. (X 140)

Fig. 5. A longitudinal section of wood showing short compressed and twisted medullary ray cells.

Kargali seam, Swang colliery, Quarry No. 2, Sample No. S/2. (X 125)

PLATE 7

Fig. 1. A more or less similar structure as that in Plate 6, Fig. 5. The medullary rays are elongated and slightly swollen at their ends.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/26. (X 170)

Fig. 2. A transverse section of thin-walled tissue showing compressed and twisted ray cells.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/5.
(X 225)

Fig. 3. A longitudinal section of wood showing large cylindrical thin-walled cells. The cells seem to be attached by a ball and socket joint. In some cases the adjoining ends are connected by tube like projections and in other cases the cells are considerably squeezed at one and both the ends.

Kargali seam, Kargali colliery, Quarry No. 3, Sample No. KK3/13.
(X 785)

Fig. 4. A transverse section of wood showing opaque granular matter in the cells. The bordered pits are characteristic and have produced X-shaped chains in the cell walls.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/82.
(X 210)

Fig. 5. A longitudinal section of woody tissue showing slightly compressed tracheids filled with opaque granular matter. The narrow pale twisted medullary ray cells.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/89.
(X 170)

PLATE 8

Fig. 1. Woody tissue slightly twisted as a result of compression. The elongated cells have their lumens filled with opaque matter. Pale coloured slightly swollen medullary ray cells are conspicuous.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/74.
(X 255)

Fig. 2. Transverse section of a tissue showing serially arranged, compressed, thin-walled cells which are invariably thickened at the corners. The cell cavities are filled with dense opaque material.

Kargali seam, Kargali colliery, Quarry No. 3, Sample No. KK3/23. (X 185)

Fig. 3. A fragment of wood cut transversely showing alternate arrangement of thin-and thick-walled cells. The pale middle lamellae and intercellular spaces are quite prominent. Often enclosed between the cells are twisted medullary ray cells.

Kargali seam, Swang colliery, Sample No. S/3. (X 170)

Fig. 4. Densely packed thin-walled cells of wood in transverse section showing the same general characters as in Fig. 3.

Kargali seam, Kargali colliery, Quarry No. 3, Sample No. KK3/23. (X 255)

Fig. 5. Transverse section of a woody tissue showing distinct middle lamellae enclosing a mass of decomposed fragmental matter. Near the lower left-hand side the durain is largely comprised of this matter.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/82. (X 170)

PLATE 9

Fig. 1. The same general features as in Plate 8, Fig. 5, are shown. The opaque finely granular matter fills the lumens here. In the central part the granular material forms a dense mass with the cell walls no longer preserved.

Kargali seam, Kargali colliery, Quarry No. 3, Sample No. KK4/3. (X 340)

Fig. 2. A twisted opaque patch in the middle of a woody tissue is quite conspicuous. The compressed fibres are also filled with a dark substance.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/75. (X 340)

Fig. 3. Woody tissue showing an advanced stage of decomposition. The elongated thick-walled cells are broken and scattered.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/88. (X 375)

Fig. 4. Woody tissue showing bogen-structure. The spaces between the fractured cells are filled with an opaque substance.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/26. (X 425)

Microtectonics in the woody tissue

Fig. 5. Woody tissue showing folded cells. The cavities of the fibres contain dark material.

Bermo seam, Dhori colliery, Sample No. BQ/8. (X 255)

PLATE 10

Fig. 1. Woody tissue showing intense crumpling of the fibres resembling an over-fold structure. A hard resin-filled cellular body is seen in the middle.

Kargali seam, Bokaro colliery, Quarry No. 2, Sample No. KB2/8F. (X 170)

Fig. 2. Woody tissue in which the fibres have been folded. The fold is fractured at several places with slight movement of the tissue along the fracture planes.

Kuju seam, Morpa colliery, Sample No. WB/M2. (X 340)

Fig. 3. A mylonised tissue of vitrinite showing angular fragments of varying size and shape. The finely divided matrix filling the interspaces is also vitrainy in composition.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/13. (X 170)

B. Bark tissue

Fig. 4. Fragments of bark in transverse section showing rectangular and rhomb shaped thick-walled cells. The middle lamellae and intercellular spaces filled with a pale substance are conspicuous.

Kargali seam, Bokaro colliery, Quarry No. 2, Sample No. KB2/8F. (X 170)

Fig. 5. Bark tissue showing alternating strands of thick-and thin-walled cells. The thick-walled cells are rectangular while the thin-walled cells are not discernible clearly.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB3/78. (X 210)

PLATE 11

Fig. 1. More or less the same features as in Plate 10, Fig. 5. The thick-walled cells are rectangular, incurved along the sides and angular at the corners. Pale middle lamellae are distinct.

Bermo seam, Dhori colliery, Sample No. BQ/8. (X 170)

Fig. 2. A thick-walled tissue of bark is broken into blocks of different size.

Bermo seam, Dhori colliery, Sample No. BQ/8. (X 170)

Fig. 3. A similar tissue as in Fig. 2. Rows of thick-walled cells have been folded.

Bermo seam, Dhori colliery, Sample No. BQ/8. (X 170)

C. Secondary bark

Fig. 4. Secondary bark tissue showing serially arranged thin-walled rectangular cells which are filled with a pale brown coal substance.

12-foot seam, Incline No. 3, Sample No. KT/7. (X 250)

Fig. 5. Transverse section of a tissue showing thin-and thick-walled cells in alternate rows. Thin-walled cells are rectangular in shape and have wider cavities. Thick-walled cells are rhomb shaped often exhibiting lamination. A few stone cells are also seen towards the lower right-hand corner.

12-foot seam, Incline No. 3, Sample No. KT/12. (X 170)

PLATE 12

FUSINITE

Fig. 1. Woody tissue preserved as fusinite showing serially arranged thick-walled rectangular cells. The cells often exhibit scalariform thickenings and the cavities are filled with a finely crystalline substance.

Jarangdih seam, Jarangdih colliery, Sample No. JJ/3. (X 170)

Fig. 2. Transverse section of a woody tissue preserved as fusinite exhibiting the same general characters as in Fig. 1.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/78. (X 170)

DURAINS

Figs. 3 & 4. Fibrous type of durain with abundant shreds and bits of vitrinite. Micrinite, microspores and finely granular mineral matter are the other constituents. A brown rounded resin in the central portion of Fig. 3 is fairly conspicuous.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/4 and KB7/74 respectively. (X 70)

Fig. 5. A similar type of durain as that in Figs. 3 and 4. Finely granular mineral matter is prominent.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/5. (X 70)

PLATE 13

Fig. 1. Durain showing three resin bodies. A twisted megaspore lies near the lower margin.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/103. (X 125)

Fig. 2. Durain showing rows of dark brown cuticles with toothed margins.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/13. (X 125)

Fig. 3. Durain formed as a result of decomposition of cell walls. A thin band of vitrinite lies across the right-hand margin.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/87. (X 125)

Fig. 4. A similar type of durain as in Fig. 3. Brown oval resins are quite common and often enclose gas bubbles and opaque granules.

Kuju seam, Kuju colliery, Sample No. WB/K5. (X 125)

Fig. 5. An opaque attritus type of durain showing an abundance of fusinite, micrinite and mineral matter.

Kargali seam, Bokaro colliery, Quarry No. 7, Sample No. KB7/22. (X 70)

PLATE 14

MINERAL MATTER

Fig. 1. A fragment of siltstone embedded in durain. Quartz and lath-like kaolinite are the chief constituents with carbonaceous matter filling the interspaces.

Kargali seam, Kargali colliery, Quarry No. 3, Sample No. KK3/9. (X 125)

Fig. 2. Durain showing a vermicular piece of Kaolinite under crossed nicols. Two directions of extinction are conspicuous.

Kargali seam, Bokaro colliery, Quarry No. 2, Sample No. KB2/12F. (Crossed nicol X 170)

Fig. 3. A group of kaolinite crystals under crossed nicols. Fibrous structure of the mineral and dark rod-like inclusions are quite characteristic.

Eastern Karo seam, Turio colliery, Sample No. T/4.
(Crossed nicols X 170)

Fig. 4. Durain showing abundance of siderite nodules.

Bermo seam, Dhori colliery, Sample No. BQ/4. (X 125)

PLATE 15

Fig. 1. A large nodule of siderite exhibiting fibrous structure in the central portion.

Kargali seam, Kargali colliery, Quarry No. 2, Sample No. KK2/28.
(X 40)

Fig. 2. A spiral tracheid replaced by siderite.

Jarangdih seam, Jarangdih colliery, Sample No. JJ/3. (X 250)

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